ELECTRIC TRACTION

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ELECTRIC TRACTION

BY

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PREFACE

THE Engineering of Electric Traction has already thrown that of Electric Lighting into the shade, and yet the development of Electric Railways has only just begun. When it has reached only the earliest stage of vigorous adolescence, it will be found to bring in its train a great further development of Electric Tramways, because then there will be recognized the fact that one of the great functions of Tramways is to act as feeders to Railways and the present antagonism between Railways and Tramways will have died out.

The progress of invention in electrical engineering is now so rapid, and especially so in regard both to Tramways and Railways, that it is hard to keep a treatise upon any electrical subject fully up to date. But in the production of this book the publishers have co-operated with the author in much effort to make it fully representative of the most recent practice right up to the date of publication. This would have been impossible except for the kind assistance in supplying the latest information and designs very generously given by numerous tramway and railway managers, chief engineers, and manufacturers. The author desires to offer his best thanks to all who have helped him in this way; and trusts that even the electrical engineer and manager of experience and detailed knowledge may find some convenience in the book, in that it collects within small bulk a large amount of scattered information in respect of at least the most practically important features of Electric Traction. The book, however, is mainly written in the hope that it may be useful in the instruction of students of technical electrical engineering.

It keeps strictly to its subject of *traction*, and leaves entirely to other treatises all explanations of electrical machinery and electrical action that are general and common to the whole of electrical engineering.

One special feature the author hopes may be regarded as a merit; namely this, that it deals not only with dynamic and constructional principles and details, but also with commercial results and economic conditions. The author holds strongly that technical students should direct their attention much more to this side of technics than is now usual. The physical side is only one half of engineering science; and no technical science will ever be rationally complete, nor will it ever win the full confidence and respect of the practical world, until it rests equally upon the two true bases of physical and economic law which *together* govern all industry.

Since this book deals with European work alone, it is necessary to say that the author has always been among those who have insisted upon the great debt that Europe owes to America in regard to Electric Traction. Although Europe, and not America, is the native home of nearly all original ideas in this department of engineering, still it was in America that the world learnt all its important early practical lessons and gained the great bulk of its first practical experience.

The reasons for confining the book to European practice have been twofold. The author labours under a constitutional inability to write about things he has not seen with his own eyes and examined for himself, while he has had very limited opportunity for more than cursory observation of Trans-Atlantic work. Then, again, the most recent and progressive developments of traction design are to be seen here, and not there. American electric-traction engineering has already become standardized and conservative: its European pupil is still eagerly striving after new and higher things.

The author has purposely kept within the range of things actually and successfully accomplished on a commercial scale. He has therefore merely made mention of proposals for single-phase traction, and has devoted only a short part of one chapter to Electric Traction on common roads. These two subjects may make great practical progress in the immediate future; but they could not find a place at present within the scope of this work.

R. H. S.

March, 1905.

CONTENTS

CHAPTER I

GENERAL SURVEY

CHAPTER II

TRAMWAYS

b

CHAPTER III

ECONOMIC DEDUCTIONS FROM STATISTICS AND TECHNICAL CONDITIONS

CHAPTER IV

OVERHEAD TRAMS

CHAPTER V

CONDUIT TRAMWAYS

CHAPTER VI

SURFACE-CONTACT TRAMWAYS

CHAPTER VII

LONDON DEEP-LEVEL ELECTRIC RAILWAYS

CHAPTER VIII

LONDON SURFACE AND SHALLOW ELECTRIC RAILWAYS

CHAPTER IX

BERLIN ELECTRIC RAILWAYS

CHAPTER X

ITALIAN DIRECT-CURRENT RAILWAYS—ELBERFELD MONO-RAIL

CHAPTER XI

HIGH-TENSION ALTERNATING-CURRENT RAILWAYS IN ITALY

LIST OF TABLES

CHAPTER I

GENERAL SURVEY

1. General Advantages of Electric Traction—2. Four Main Classes of Traction—3. Secondary Batteries—4. Costs of Electric Automobilism—5. The Edison Battery—6. Continuous and Alternating Current—7. Low and High Tension—8. Transformers and Sub-stations—9. Detailed Sub-classification of Electric Tramways—10. Ditto of Electric Railways—11. *Résumé* of detailed General Classification.

1. THE merits of Electric Traction as compared with horse and steam-locomotive traction are (1) cleanliness of the roads and of the atmosphere over and through which the traffic runs, (2) cleanliness and comfort of the carriages, (3) facility for serving a dense traffic by the frequent dispatch of cars or small trains as against the dispatch of long heavy trains at long intervals, (4) smoother and less jolty riding, (5) less cost, (6) greater feasibility of frequent stops and starts, (7) quicker acceleration in starting and less loss of power in rapid stopping, (8) less risk of accident, and (9) less cost per mile travelled by each passenger carried, *i.e.* "per passenger-mile."

2. There are in use various kinds of electric traction, and naturally each of the above merits appears in more or less prominence in the different kinds. In present practice these kinds may be classified as—

(A) Common Road Traction;
(B) Tramways;
(C) Railways;
(D) Boat Propulsion.

There are possibilities in the direction of the electric driving of kites and boats through the air, if utilities can be discovered for so uncomfortable and dangerous methods of travelling; but they need not now be further considered. The electric propulsion of boats is confined to water traffic. It takes place by two methods, giving the sub-classification (D*a*), boat and barge propulsion along canals, in which motors placed in the boats may be supplied with energy through wires stretched alongside the canal; and (D*b*), launches and

other boats used for travel anywhere and in any direction on lakes, rivers, harbours, etc., in which the motive energy must be carried in the boat by means of storage batteries. Such boats cannot travel great distances beyond the range of stations at which their batteries can be re-charged.

Class (A), common road traction, may, in the distant future, be capable of similar sub-classification. But at present road vehicles of all kinds for use on ordinary highways are necessarily dependent for their motive energy upon storage batteries carried along with, and in, the vehicle itself. This limits their range of travel, the greatest journey at present accomplished on a single charge being from 80 to 100 miles, while 30 to 40 miles is a much more economical range; and it also makes the weight of the vehicle great in comparison to its passenger, or goods, carrying capacity. A still greater difficulty is the destructive influence upon the battery of the jolting to which the carriage is exposed by the inequalities of the road surface. This injury is primarily mechanical, but the mechanical disintegration of the plates is disastrous to the efficient electro-chemical action upon which the reproduction in active form of the stored energy depends.

3. For many years, therefore, the main efforts of engineers engaged in this department of work have been devoted to two points: firstly, to the improvement of the mechanical construction of the accumulator, or secondary battery, plates, rendering them less easily disintegrable by vibration and shock; and secondly, to improved suspension of the battery as a whole in the carriage frame in such manner as to insulate the former from transmission of vibration, and to damp down such vibration as is transmitted to waves of softer outline and slower period. Along with this is combined the endeavour to reduce the weight of the battery per watt-hour capacity—that is, per unit of energy it is capable of storing and re-storing. The efficiency also of secondary batteries is low, and has to be improved before they can be extensively used for traction. Leakage is one source of inefficiency which it is difficult to obviate entirely. But independently of all current leakage, the ratio of the current-energy usefully restored to that expended in charging the battery is largely influenced by the time-rate at which the discharge takes place. In traction upon common roads the demand for driving power varies rapidly through excessively large range. If, throughout the whole period of discharge, the degree of exhaustion of each individual cell in a battery of a great many cells were accurately known, then, by help of a suitable switch-board, there would be a theoretical possibility of so manipulating the use of the battery as to maintain the discharge of each cell at nearly the rate of maximum efficiency. But to make such manipulation practicable in traction work, the switching would need to be automatic —that is, independent of skill, judgment, or even attention to specific

rule, on the part of the driver; and such automatic action is unlikely to be easily or cheaply attained.

In the existing stage of progress these difficulties still prevent electric traction being largely used on common roads. In special circumstances its use is practicable and advantageous. When economy in capital outlay and in depreciation of capital value is not of first importance as compared with readiness to start without any delay on short runs at unexpected times and with smooth running and ease of safe manipulation by unskilled hands, as, for instance, in the case of visiting doctors' service in which it is of great convenience to be able to start at any hour of the day or night without the assistance of a groom or driver, then the use of secondary-battery motive power offers great advantage. It is more applicable within the limits of large cities where charging stations are dotted about not very far apart. It has special convenience for ladies who wish to drive themselves unaccompanied by a "driver." Very similar services, to which, however, the method has not yet been applied, are those of fire-engines and life-boats. An auxiliary secondary-battery starting plant would very greatly increase the effectiveness of fire-engine service, the steam-pumping plant coming into operation later.

In common road traction electric power has to compete with horse-power, with steam-power, and with internal-combustion oil-engine-power. In the second case either anthracite coal, coke, or oil fuel may be used under the boiler. As regards weight of driving plant to be carried, the boiler, with its furnace and chimney, coal-bunker, and water-tank, together with the engine, in the one case, has to be compared with the secondary battery along with the electro-motor and its reducing gear in the other; while with the oil-engine there is the combined weight of oil-tank, engine, and reducing gear. The last combination has decided advantage over either of the two others in point of weight. The oil-engine, in good working condition, takes much less time to get ready for a start than does the steam plant, but is not so ready as is the secondary battery, and is also not so quickly and easily stopped and re-started *en route* as is the electro-motor. The electric automobile has the unique advantage of leaving no smoke, gas, dirt, or smell in the streets behind it.

The field to be competed for is a very large one. A number of secondary-battery cabs were placed on the London streets a few years ago. They were withdrawn on account of the vibration trouble with the battery and of the excessive wear of the chain-gear employed. They are reported to have cost in total expenses 32*s.* per day, while their gross earnings amounted to 23*s.* An enormous number of mechanically driven shop-delivery vans, parcels vans, and post-office vans will be used so soon as an entirely satisfactory and reasonably cheap design is procurable. An almost equally ready

demand for mechanically driven omnibuses is waiting to be satisfied. Electric traction is likely never to have any chance in the competition for the heavy waggon and lorry traffic.

At the Engineering Conference of the Institute of Civil Engineers of 1903, Lieut.-Col. R. E. B. Crompton read a short paper entitled, "Applications of Electricity to Driving Carriages in Towns." He considers that one leading advantage possessed by electric drive is the ease with which the motive power may be applied to the front wheels, which reduces risk of side-slipping. In his opinion the question of reduction of cost is to be met by standardization of accumulators and by a system of widely scattered charging stations, where exhausted accumulator boxes may be exchanged for fully charged boxes. For a reason not yet well ascertained the cost of repairs of the tyres of electrically propelled vehicles is higher than in steam and oil-driven carriages. The Paris hired broughams, electrically driven, cost in tyres about £1 per 100 miles run, while the driver and garage cost together another £3. The batteries mostly in use deteriorate in value from 50 to 80 per cent. per annum, the lighter ones depreciating most rapidly. Besides the effect of vibration, loss of capacity results from over-discharge—that is, from the custom of nearly exhausting the charge in running before re-charging, instead of re-charging after about half of the stored energy has been spent. Re-charging should take place as soon as the external voltage has fallen to 1·8 volts per cell.

The table (on p. 5) of the capacities of the batteries manufactured by various firms is given on the authority of M. Henri L. Joly. Its date is 1903, and it does not include the new Edison battery. The capacity is given in "ampère-hours," and it is assumed that the discharge is at a uniform rate of 30 ampères; so that 150 ampère-hours means 30 ampères maintained for 5 hours. The actual current, or rate of discharge, varies according to the ohmic resistance and the back electromotive force inserted in the circuit.

It will be noted that the table gives one case in which the capacity is over 7½ ampère-hours per lb. of weight; but between 4 and 5 is the usual figure. A more exact measure of capacity is the watt-hours, because the external voltage depends upon the internal resistance of the cell, and this varies with the size and arrangement of the plates, and also with the current discharged. The watt-hours per lb. of weight varies largely—from 8 to 15 or 16. The external voltage, and, therefore, the external watt-hours capacity, of a battery of many cells depends upon the grouping of the cells in the battery, and one common method of controlling the speed and horse-power of the car is by a switch which alters this grouping. When not stated, the average discharge voltage is assumed as 2 volts, so that the watt-hour capacity may be taken as twice the ampère-hour capacity.

TABLE I.

	Ampère-hours 30 A rate.	Dimensions over all.					Ampère-hours per lb. weight.
		Height.	Width.	Length.	Weight.	Floor space.	
		ins.	ins.	ins.	[illegible]	sq. ins.	
E.P.S. . . .	150	12⅝	4⅜	5½	32	24	4·7
Hart . . .	130	12	3⅝	8	27	29	4·8
Leitner . .	150	10	4⅜	6¼	30	27·5	5·0
Lithanode . .	120	10	4¾	6¼	32	30	3·75
Rosenthal . .	180	10	4	6⅜	23½	25	7·65
Tudor . . .	137	12¾	6	6½	34	39	4·0
Exide . . .	150	11½	4¼	6 3/16	31½	26	4·75
Gould . . .	150	11½	4¼	6¼	29¾	26·5	5·0
Helios Upton .	150	10⅝	4 3/16	6⅝	27	27·5	5·5
Porter . . .	150	10	4⅛	5¼	25	21·75	6·0
Contal . . .	150	11¾	4⅝	4¾	24	22	6·2
Fulmen . .	150	10	4⅜	7	28	39·5	4·4
Heinz . . .	150	11¾	4⅝	6¼	31	27·2	4·9
Max . . .	150	11⅜	4⅛	6¼	26·5	25·7	5·6
Phenix . . .	150	11¾	3¾	7¼	27·5	27	5·4
Akkummulatoren Akt. Ges. Boese	150	11¼	5¾	7½	47½	43	3·2
Berliner Akt. Ges.	150	12 3/16	4½	7⅜	32	33	4·7

The efficiency of secondary batteries, or the ratio of the energy recovered to that charged into them, falls off after many repetitions of the process of charge and discharge. At first it may be from 70 to nearly 80 per cent., and it gradually falls to from 50 to 60 per cent.

The energy required to drive road electric vehicles is commonly measured as so many "watt-hours per ton-mile," the ton-mileage being the product of total load and the distance run. The watt-hours per ton-mile varies, (1) with the up or down gradient of the road, (2) with the wind adverse or favourable, and (3) with the character and condition of the road surface. It varies somewhat, but slightly, with the diameter of the wheels; and very much more with the kind of gearing employed, its good or bad manufacture, and its condition of cleanliness and lubrication. As little as 50 or 60 watt-hours per ton-mile, at a speed of 6 miles per hour, on a level, smooth road without head wind has been authenticated; but over 200 is often required on a level road. The average, under all ordinary circumstances, seems to lie between 140 and 150; but with simplification

and other improvement of the gearing, there is no reason why this should not be reduced to an average between 80 and 100.

As a "ton-mile" is a measure of the same kind as "work" or "energy," the above ratio of watt-hours per ton-mile is a pure numerical ratio. It is really the ratio between the work done to propel the vehicle any distance to the work that would be required to lift it without frictional resistance vertically through the same distance: except that the strangely irrational mixture of metric and British measures introduces an arbitrary numerical factor. One horse-power-hour equals $60 \times 33{,}000 = 1{,}980{,}000$ ft.-lbs. $= \dfrac{1{,}980{,}000}{2240 \times 5280}$ mile-tons = about $\frac{1}{6}$ of a mile-ton, or ton-mile, as it is more usually called. Therefore, 1 horse-power-hour per ton-mile would mean that the work done in propelling the vehicle is $\frac{1}{6}$ of that needed for frictionless lifting of the total weight of the vehicle and its load through the same vertical height. One electrical Board of Trade Unit is $1\frac{1}{3}$ horse-power-hours, and 100 watt-hours is $\frac{1}{10}$ of one B.T.U. Therefore 100 watt-hours per ton-mile means that the propulsive work done equals $\frac{1}{6} \times \frac{4}{3} \times \frac{1}{10} = \frac{1}{45}$, that needed for vertical lifting through the same distance: otherwise equals the work done on gravitation alone on an up-gradient of 1 in 45. The measure, therefore, reduces, in essence, to the ratio between the actual propelling or tractive force to the total load propelled, and does not really involve any reference to either distance or speed. The ratio between these two forces is influenced by speed, and in an important degree when the speed rises much above 10 or 12 miles per hour, and also at lower speeds against a head wind. But it is desirable to bear in mind that 100 watt-hours per ton-mile means no more than that the driving force, reduced to a tangential effort at the periphery of the driving-wheel, is $\frac{1}{45}$ of the total load; and that 1 horse-power-hour per ton-mile means no more than that this ratio is $\frac{1}{6}$. On a gradient of 1 in 9 the tractive effort required to overcome gravity alone would be $\frac{45}{9} \times 100 = 500$ watt-hours or $\frac{1}{2}$ kilowatt-hour per ton-mile; and on a gradient of 1 in 6, the tractive effort to overcome gravity alone would be 1 horse-power-hour per ton-mile. Or otherwise stated, an extra 45 watt-hours per ton-mile is required for every 1 per cent. in the up-grade.

The measure 100 watt-hours per ton-mile may often be most conveniently thought of as 100 watts per ton-mile per hour—that is, 100 watts for each ton of load drawn at the speed of 1 mile per hour. This is the same rate as 1 kilowatt for each ton of load at 10 miles per hour.

Similarly, 1 horse-power-hour per ton-mile means also 10 horse-power for each ton of load at 10 miles per hour speed; a power rate about $7\frac{1}{2} = \frac{45}{6}$ times as great as 1 kilowatt for the same service.

If, exclusive of climbing work, 150 watt-hours per ton-mile be assumed as the average needed for propelling road-vehicles, and if 10 watt-hours be taken as the capacity of storage batteries per lb. of their weight, then evidently 15 lbs. weight of battery will be needed per ton-mile of duty to be done on one charge of the battery. This, however, is an under-estimate of actual requirements; extra provision has to be made for climbing.

The ratio of the weight of carriage, exclusive of battery, as now built, to that of the passenger load varies from 2 to 4; and the battery weighs from $\frac{1}{2}$ to $1\frac{1}{2}$ times as much as the carriage, the average being nearer the lower than the higher ratio. Thus the total load, inclusive of passengers, is from 4 to 10 times the useful load or weight of passengers carried.

4. The cost of electric automobiles is not now so great as it was only a few years ago, and it is hoped that it may be further greatly reduced. At present good carriages may be had for about £150 per 1000 lbs. in weight of carriage, plus from £55 to £65, or average £60 per 1000 lbs. in weight of battery.

Interest, repairs, and depreciation upon the car, exclusive of battery, and exclusive of tyre renewals and repairs, may together be taken as 20 per cent. per annum, or $\frac{20}{300} = \frac{1}{15}$ per cent. per day, assuming 300 running days per year, which assumption means that the vehicle is very steadily and regularly employed. This means a cost of £$\frac{150}{1500}$ = 2*s.* per day per 1000 lbs. of car weight.

The same items of cost on the battery vary greatly according to the make of the battery, its mode of suspension, and the character of the roads traversed. Seventy-five per cent. per year, or $\frac{75}{300} = \frac{1}{4}$ per cent. per day, is not too much to allow as an average. This yields a cost of £$\frac{60}{400}$ = 3s. per day per 1000 lbs. of battery weight.

The driver's wages and stabling charges amount roughly per day to 3*s.* 6*d.*, plus 1*s.* 9*d.* for each 1000 lbs. in the combined weight of car and battery. Of this item $\frac{6}{7}$ are due to the driver, and this may be omitted if no driver be kept.

The costs already mentioned depend little, or not at all, upon the mileage run per day. Summing them up, they may be represented fairly closely by the formula—

$$3s.\ 6d.\ \{1 + C + B\} \text{ per day}$$

where C and B are the weights of the vehicle and of the battery measured in units of 1000 lbs.

But if a driver be dispensed with, these costs will be reduced to about—

$$6d. + 2s.\ 6d.\ \{C + B\}$$

The repairs and renewals of tyres, oil, and similar running costs,

are about $\frac{1}{2}d.$ per mile per 1000 lbs. of load; and the cost of energy may be taken as averaging $\frac{1}{4}d.$ per same unit, although the prices at the charging stations and the efficiencies of the batteries and of the gearing vary very greatly.

Thus if M miles be run per day, the total cost per mile will be—

$$\tfrac{3}{4}d.\ \{C + B + P\} + 3s.\ 6d.\ \frac{1 + C + B}{M}$$

where P is the passenger load in 1000 lbs. units.

Reducing this to per 1000 lbs.-mile of *total load* by dividing by $\{C + B + P\}$, the cost is—

$$\tfrac{3}{4}d. + \frac{3s.\ 6d.}{M} \cdot \frac{1 + C + B}{P + C + B}$$

If M = 21 miles per day on the average, this becomes—

$$\tfrac{3}{4}d. + 2d.\frac{1 + C + B}{P + C + B}$$

Reducing it to per 1000 lbs.-mile of *useful load* by dividing by P, it becomes in pence—

$$\tfrac{3}{4} + \frac{42}{MP} + \left(\tfrac{3}{4} + \frac{42}{M}\right) \cdot \frac{C + B}{P}$$

where $\frac{C + B}{P}$ ranges from 3 to 9.

The useful load P may average 7 or 8 passengers per 1000 lbs. Putting the number of passengers at N = 7P, and dividing the cost per mile by N, there is found the cost in pence per passenger-mile—

$$0{\cdot}11 + \frac{42}{MN} + \left(\tfrac{3}{4} + \frac{42}{M}\right) \cdot \frac{C + B}{N}$$

where $\frac{C + B}{N}$ may range from $\frac{1}{2}$ to $1\frac{1}{2}$.

The supposition here is that the full load of passengers is carried.

Although the weight of carriage and battery bears a ratio to the number of seats which varies greatly according to style of build, and its ratio to the actual number of passengers in any particular trip must vary very much more, still a rough average law for full passenger load is formulated thus: $C + B = 1 + \frac{N}{2}$. This makes $\frac{C + B}{N} = \frac{1}{2} + \frac{1}{N}$, varying from $1\frac{1}{2}$ for one passenger only to 0·6 for 10 passengers, and 0·55 for 20 passengers.

Using this approximate value of $\frac{C+B}{N}$ in the last given formula, then, on the assumption that the full complement of N passengers are carried on the average M miles per day on 300 days in the year, the cost per passenger-mile in pence is expressed by the fairly simple formula—

$$\tfrac{5}{16} + \left(\tfrac{1}{4} + \frac{28}{M}\right)\left(\tfrac{3}{4} + \frac{3}{N}\right)$$

The following table gives the costs per passenger-mile calculated from this formula :—

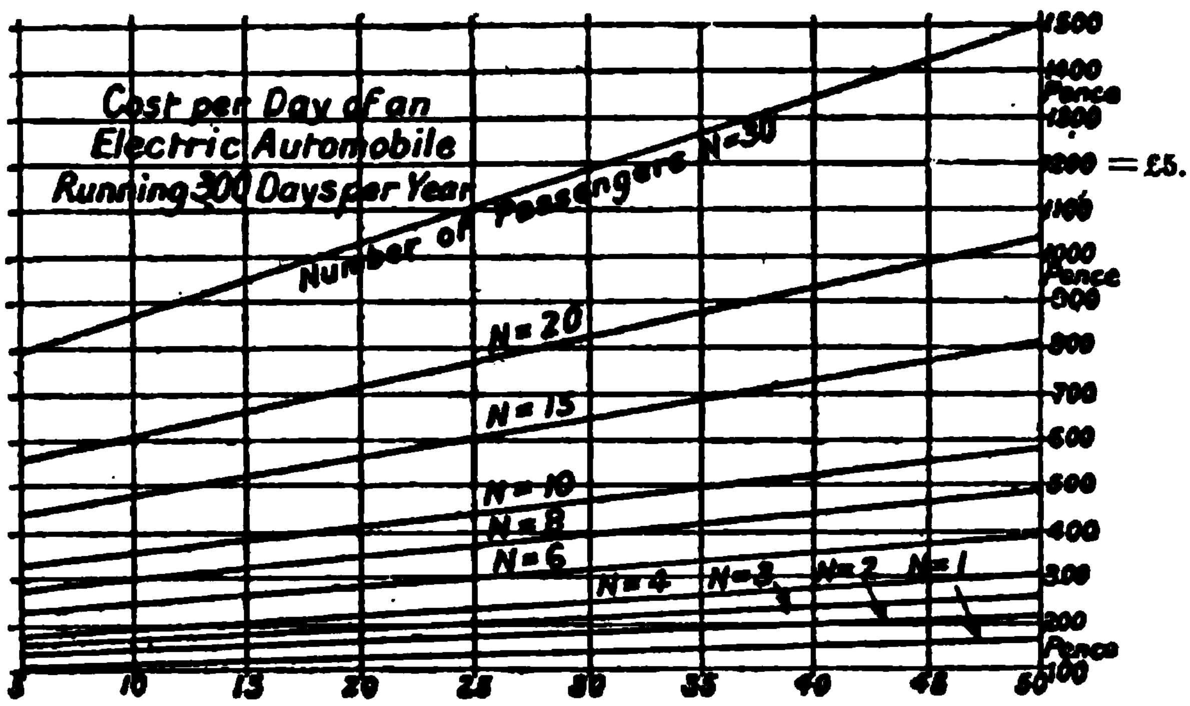
TABLE II.—COST PER PASSENGER-MILE OR PER SEAT-MILE FOR A FULL COMPLEMENT OF N PASSENGERS CARRIED AN AVERAGE DISTANCE M MILES ON 300 DAYS PER YEAR.

$0{\cdot}25 + \frac{28}{M} =$		3·05	2·11	1·65	1·18	0·95	0·81
	M =	10	15	20	30	40	50
$0{\cdot}75 + \frac{3}{N}$	N	Pence per Passenger-mile.					
3·75	1	11·75	8·22	6·50	4·73	3·87	3·35
2·25	2	7·17	5·06	4·02	2·96	2·45	2·13
1·75	3	5·65	4·00	3·20	2·38	1·97	1·73
1·50	4	4·89	3·47	2·79	2·08	1·74	1·53
1·25	6	4·12	2·95	2·37	1·79	1·50	1 32
1·125	8	3·74	2·68	2·17	1·64	1·38	1·22
1·05	10	3·52	2·52	2·04	1·55	1·31	1·16
0·95	15	3·21	2·32	1·88	1·43	1·21	1·08
0·90	20	3·06	2·21	1·80	1·37	1·17	1·04
0·85	30	2·90	2·10	1·72	1·32	1·12	1·00

The table illustrates well how advantageous in point of cost it is to run many miles per day, and to carry many passengers in the one vehicle. It starts with just under 1*s.* for a 1-seat car running only 10 miles per day, and goes down to 1*d.* for a 30-seat omnibus running 50 miles per day. The figures in this lower end of the table are, however, purely speculative, as large passenger vehicles of this size have not yet been run anywhere at this rate.

To find the cost per day for any case, multiply the proper number taken from the table by NM.

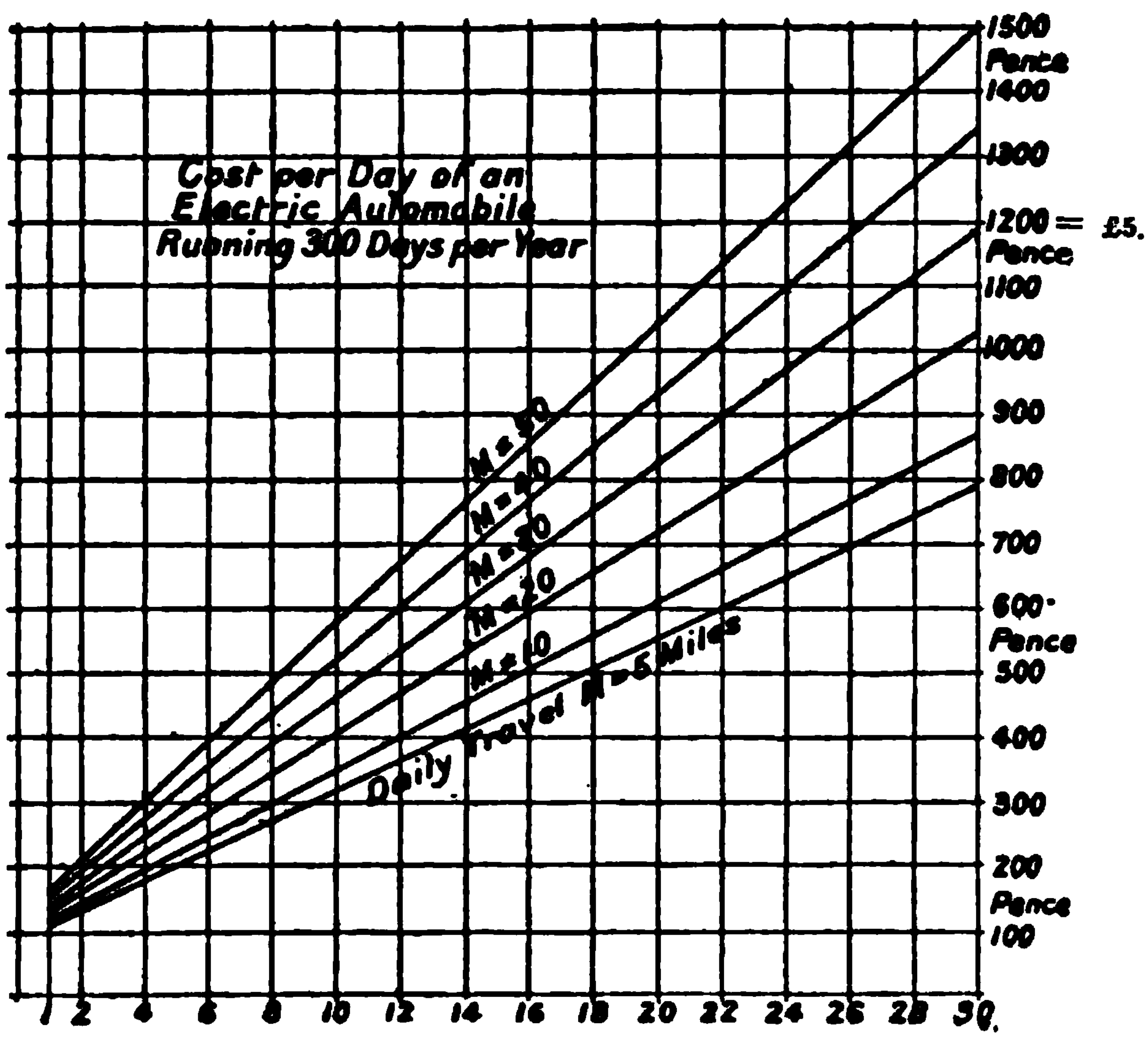
For any given number of seats this total cost per day increases by a straight-line law with the distance run per day. Thus the cost per



M = Daily Mileage.

FIG. 1.

day of a 1-seat car is 10*s.* at 10 miles per day, and an extra 1*s.* 0½*d.* for every extra 10 miles per day; while a 10-seat car costs 29*s.* 4*d.*



N = Number of Seats.

FIG. 2.

per day at 10 miles per day, and an extra 4*s.* 9*d.* for every extra 10 miles per day.

Similarly, for any given number of miles per day the total cost per day increases by a straight-line law with the number of seats or carrying capacity. Thus at 10 miles per day, the car with one seat costs 10*s.* per day, while the cost per day increases by 2*s.* 2*d.* for every extra seat. At 20 miles per day, the cost per day of a 1-seat car is 11*s.*, while this cost per day increases by 2*s.* 7*d.* for every extra seat.

The straight line showing the cost per day of a given car for different distances run daily, is represented by the equation.

$$\text{Daily cost in pence} = 84 + 21\text{N} + (\tfrac{3}{4} + \tfrac{1}{2}\text{N})\text{M}$$

For a 1-seat car, this becomes	$(105 + 1\tfrac{1}{4}\text{M})$
„ 4 „ „ „	$(168 + 2\tfrac{3}{4}\text{M})$
„ 10 „ „ „	$(294 + 5\tfrac{3}{4}\text{M})$
„ 20 „ „ „	$(504 + 10\tfrac{3}{4}\text{M})$

increasing by $(21 + \tfrac{1}{2}\text{M})$ for each extra seat.

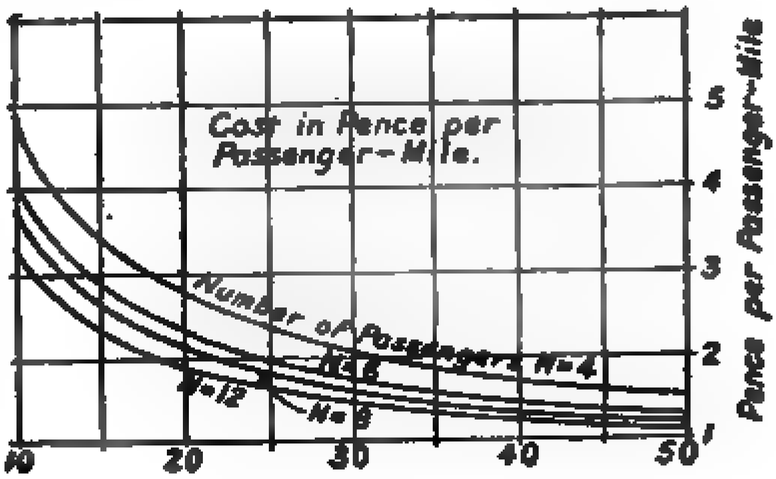
The straight line showing how the daily cost for a given daily distance increases with the size of the car has the equation—

$$\text{Daily cost} = 85 + \tfrac{3}{4}\text{M} + (21 + \tfrac{1}{2}\text{M})\text{N}$$

For 10 miles per day, this becomes	$(91\tfrac{1}{2} + 26\text{N})$
„ 20 „ „ „	$(99 + 31\text{N})$
„ 30 „ „ „	$(106\tfrac{1}{2} + 36\text{N})$
„ 40 „ „ „	$(114 + 41\text{N})$
„ 50 „ „ „	$(121\tfrac{1}{2} + 46\text{N})$

increasing by $(7\tfrac{1}{2} + 5\text{N})$ for each extra 10 miles per day.

Figs. 1, 2, 3, and 4 illustrate these various laws very clearly. They show that little or no economic advantage is obtained by increasing the size of the cars beyond 8 to 12 seats; but that the maintenance of a high average mileage per day is of the greatest possible influence in reducing the cost per passenger mile.



M = Daily Mileage.

Fig. 3.

The motors used are, of course, continuous-current motors. To supply a large torque for quick starting they should be series wound, or, if compound wound, should have ample series ampère-turns on the field. It would be

desirable to arrange for cutting out some of the series field-winding after speed has been got up. Shunt-wound motors have the advantage that, while descending hills at high speed, they may be used as dynamos, reversing the current and feeding into the battery so as to recuperate its store of energy. The energy so restored to the battery comes from gravitation work in the descent of the weight of the carriage to lower level. Similar recovery may be obtained during the stoppage or slowing of the car by electrical brakeage, the motor acting as dynamo. A shunt-wound motor is ineffective in starting; but there seems no good reason why both series and shunt

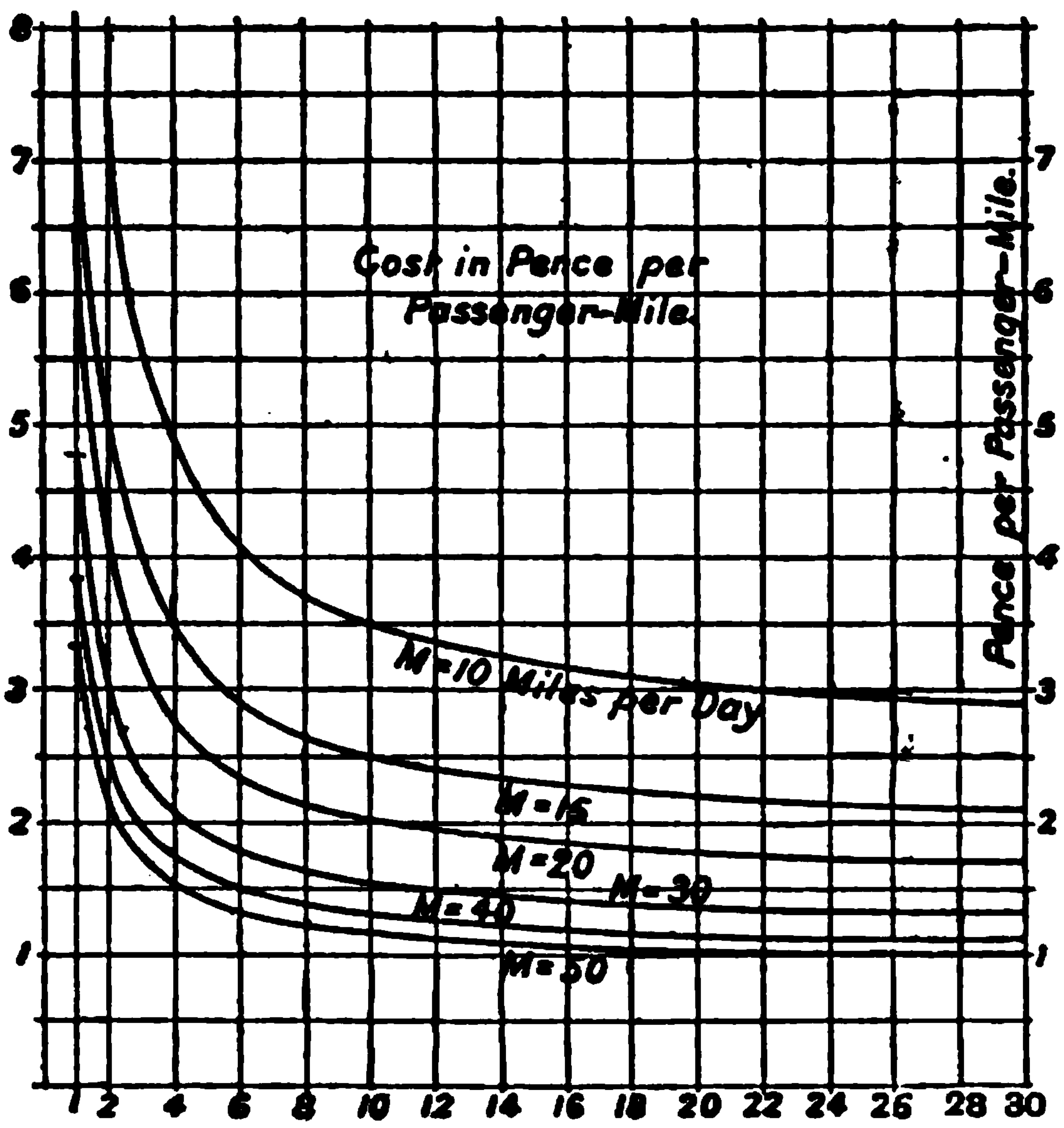


FIG. 4.

windings should not be used in sufficient strength to perform the two functions separately, the whole or the major part of each winding being cut out according to the duty to be performed. The motor action is reversed to that of a generator dynamo, when the back E.M.F. becomes greater than the driving E.M.F. of the battery. This latter may be reduced by switching the groups of cells from series into parallel arrangements. The back E.M.F. is conjointly proportional to the speed and to the strength of field. The strength of the series field is weakened as the back E.M.F. increases, and the series field would be reversed as soon as the armature current were reversed if

the series windings were not cut out before this took place. The shunt field, however, is not so affected; its strength rises slightly as the back E.M.F. increases, and its direction is not reversed when the main current is reversed. In recuperating while running down hill at high speed, the shunt field fulfils well the function desired; but in slowing down by electric braking, it is desirable because of the low speed to arrange for the decrease of the battery E.M.F., and also so far as possible for the strengthening of the shunt field on the motor. Evidently the final braking to stoppage cannot be performed electrically.

5. For several years Mr. Thomas Edison has devoted the resources of his laboratory to the production of a new design of battery especially suitable for electric traction. To obtain mechanical strength he builds the active plates upon thin perforated sheet steel. Into each perforation, which is of rectangular shape, is inserted a portion of one of the two active elements held in a metallic grid frame or finely slotted case. Each of these small cases can be removed from the plate and replaced individually. All the perforations in one plate are filled with the positive element, which is peroxide of nickel mixed with flake graphite. An equal number of small cases of finely powdered iron mixed with graphite are placed in the perforations of the opposite or negative plate. The electrolyte is a solution of potash of 20 per cent. strength. The plates are kept apart from each other and from the walls of the cell by rubber pads. These walls, which are of corrugated steel, form a box of rigid form, which box is hermetically closed over the top. The connecting terminals issue by the top through rubber glands, which are tight against leakage of the electrolyte. The terminal coupling is made by conical pin and socket held together by a screw and nut. Gas generated during charging finds vent by a gauze nipple covering a valve held down by its own weight until the gas pressure lifts it. A cell of 14 pairs of plates weighs about $17\frac{3}{4}$ lbs., and yields over 200 watt-hours at $1\frac{1}{3}$ volts, or between 11 and 12 watt-hours per lb. of complete cell. Thus although the external potential difference, or P.D., of this cell is low, its energy storage capacity is greater than the average of the batteries of Table I. The energy discharged is less affected by the rate of discharge than in most other batteries; and, even with a twofold overload, its efficiency falls very little.

Fig. 5 gives the results of Mr. Hibbert's laboratory tests of the cell as given in his paper before the Institution of Electrical Engineers in November, 1903. This shows that the electromotive force, plus internal resistance, to be overcome in charging with 60 ampères is about $1\frac{2}{3}$ volts. During discharge, the external P.D. starts at $1\frac{1}{2}$ volts if the standard rate of 30 ampères be used, and is still $1\frac{1}{3}$ volts if as much as 200 ampères be taken off. It falls rapidly until 25 to

35 ampère-hours have been taken, and then falls slowly until from 100 to 150 ampère-hours have been run out according to the rate of discharge. At the end of this slow fall the voltage is still $1{\cdot}2 = 0{\cdot}8 \times 1{\cdot}5$ if the discharge be maintained at 30 ampères, and about 1 volt with 120 to 200 ampères discharge. After 100 ampère-hours have been spent, the voltage may be taken as $(1{\cdot}32 - {\cdot}00016a)$, where a is the ampèrage that has been maintained in the discharge. The battery ought to be re-charged before it is exhausted beyond the point in the curve in Fig. 5, where the voltage begins to fall rapidly. This point is not accurately defined, but it may be taken as $\left(160 - \frac{a}{10}\right)$. Up to this point the mean voltage varies from about $1{\cdot}30$ for $a = 30$ ampères to $1{\cdot}13$ for $a = 120$, and follows very nearly

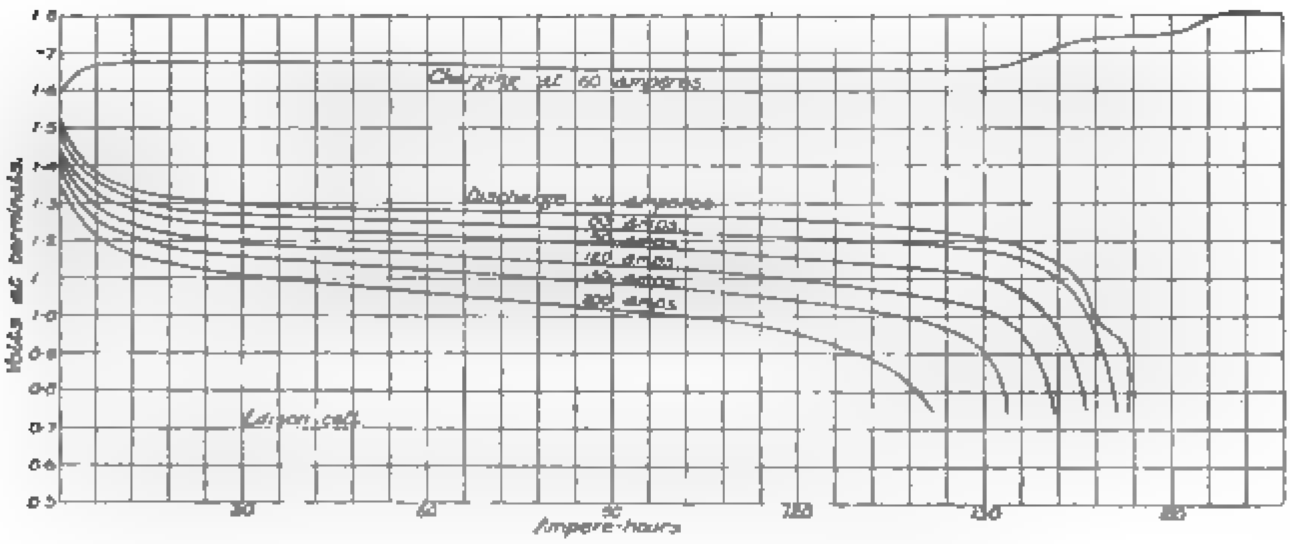


Fig. 5.—Laboratory charge and discharge of Edison cell.

the law $1\frac{1}{3}\left(1 - \frac{a}{1000}\right)$ volts. Up to this point of exhaustion, therefore, the watt-hours discharged equals very nearly $\left(210 - \frac{a}{3}\right)$. This equals—for rate of discharge, 30, 60, 90, 120; watt-hours, 207, 204, 201, 198.

In charging, the electromotive force required at the terminals averages $1\frac{2}{3}$ volts in Fig. 5. It equals the real or internal electro-chemical counter-electromotive force of the cell plus that needed to overcome the internal electric resistance of the cell. There is no direct method of measuring separately the E.M.F. of the cell and its internal resistance. Only the P.D. external to the battery can be observed, and it is this P.D. between its terminals that must be understood to be quoted in all reports of tests. Several indirect methods of analyzing this terminal P.D. into internal E.M.F. and

internal resistance have been used. It is often assumed that the E.M.F. is the same as the electrostatic P.D. measured at the terminals "on open circuit"—that is, when no current is traversing the battery; but this assumption is too irrational to deserve notice. On open circuit no chemical action is proceeding, and the electro-chemical P.D. is not likely to be the same when action is proceeding as when it is stopped. Another method of reckoning is to assume that the internal ohmic resistance remains the same under varied working conditions—that is, with various rates of discharge—and assume also that the real E.M.F. also remains the same under the like changed conditions. Thus, if r be the internal resistance at two different rates of discharge, a_1 and a_2, which show two P.D.'s, V_1 and V_2, at the terminals, then, since a part of the E.M.F., equal to ra_1, or ra_2, is spent in overcoming the ohmic cell resistance—

$$\text{the E.M.F.} = V_1 + ra_1 = V_2 + ra_2.$$

$$\text{Hence } r = \frac{V_2 - V_1}{a_1 - a_2}$$

Applying this formula to readings taken from Fig. 5 by two pairs of curves, namely, 30 and 90 ampères, and 90 and 150 ampères, and taking the differences of height between these two pairs, first at the 30 ampère-hour stage of exhaustion, and then successively at the 60, 90, and 120 ampère-hours stages of exhaustion, the following values of r, the internal resistance of the Edison cell, are obtained :—

Stage of exhaustion. Ampère hours.	r in ohms from $a_1 = 90$ and $a_2 = 30$.	r in ohms from $a_1 = 150$ and $a_2 = 90$.
30	0·0010	0·0013
60	0·0012	0·0015
90	0·0013	0·0017
120	0·0017	0·0019

It is not here assumed that the real E.M.F. is the same at different stages of exhaustion, but it is assumed that it is the same for different currents through the cell at the same stage of exhaustion. These assumptions may be tested, however, because the same calculation gives—

$$E = V + ra = \frac{V_2 a_1 - V_1 a_2}{a_1 - a_2}$$

Applying this formula to the readings of Fig. 5, we find that at

all three stages of exhaustion, 60, 90, and 120, the E.M.F. calculated from the first pair of curves at 30 and 90 ampères is exactly 1·31 volts; but calculated from the other pair of curves at 90 and 150 ampères, the E.M.F. is 1·36 volts at 60 ampère-hours exhaustion, 1·34 at 90, and 1·32 at 120 ampère-hours exhaustion. This indicates pretty clearly that, after the early stages are passed, the real E.M.F. is not affected by further exhaustion of the cell; while, on the other hand, the internal resistance increases with the current somewhat less than is shown by the above table of calculated values, and this increase dwindles to zero at the later stages of discharge. But at the very early stages of discharge evidently the E.M.F. rises very considerably above 1·31; the external voltage alone is much above this level.

Yet another possible assumption from which to calculate the internal ohmic resistance would be to assume that the counter E.M.F. in charging equals the direct E.M.F. in discharging at similar stages of development and exhaustion. On this assumption, combined with the other, that the ohmic resistances to the direct and the reverse currents are equal, the difference between the external terminal voltages during charging and discharging would equal twice the product of the current and the cell-resistance. Thus, in Fig. 5, the charging current is 60 ampères, and at, say, 90 ampère-hours, the difference between the two voltages is $1{\cdot}65 - 1{\cdot}23 = 0{\cdot}42$, and $\frac{0{\cdot}42}{2 \times 60} = 0{\cdot}0035$. This is from two to three times greater than the resistance determined by the other method. The great difference clearly proves that the E.M.F. in a secondary battery is not a wholly elastically reversible quantity, and that the difference between charge and discharge is not simply due to ohmic resistance; there is internal resistance in addition to ohmic resistance. There is chemical hysteresis, and a viscous time-lag in the reversion of the electro-chemical process. This is otherwise evident, because the electric work done in overcoming ohmic resistance is wholly spent in heating, while the heat generated in the cell by the passage of the current does not account for the whole loss of energy as between the charge and discharge. The inefficiency is due to other changes that take place besides the ohmic heating of the electrolyte and the plates, these other changes being chemical and affecting the constitution of both the electrolyte and the + and − plates. This is the reason why secondary batteries gradually lose their storage capacity even when exposed to no mechanical disintegration by shock and vibration. The Edison cell has no chemical superiority over others that have been long in the market. The improvement effected in it is in mechanical strength against deterioration by shock and vibration, and consequent decrease of the charges for repair and depreciation per mile run in a car.

This short sketch of the essential features of common road electric

traction, as it exists at the date of writing, has been introduced here because it is not proposed to deal further with this subject in the present volume. This department of electric traction is in a condition of rapid change and development, and it is expected to reach, within a comparatively short period, a much more stable condition. It has, therefore, been thought better to postpone its detail treatment to a subsequent volume of this treatise; and no illustrations of cars and their detail construction are now given for the same reason.

Returning now to our primary classification of electric traction, we have still to deal with the sections (B) Tramways and (C) Railways.

6. At the present time all electric tramways are worked by continuous or "direct" current, usually referred to as "D.C." On the other hand, both "D.C." and alternating current, or "A.C.," are used extensively on existing railways. The "A.C." may be single-phase, two-phase, or three-phase.

7. The distinction here mentioned refers to the working current that enters the motors on the cars and locomotives. But this current is at comparatively low tension—that is, the required horse-power or kilowatts is obtained from a comparatively large current at comparatively low voltage. The reasons for this are threefold. Firstly, high voltage in the cars and in the exposed conductors from which the current is collected, is considered to be more dangerous in respect of accident to employés and to the passenger public. Secondly, the insulation of the motors becomes more difficult and expensive the higher the voltage at their terminals. Thirdly, the "collection" of current from the conducting wires or rails is supposed to be more difficult at higher voltage, although there appears to be no very conclusive experimental proof of this.

The low voltage at which the energy is brought into the cars varies from 500 to 650 on tramways and D.C. railways. On the latter it is not likely ever to be raised above 700, or at most 750. On A.C. railways the highest line voltage that has been used is 3000 on the Ganz 3-phase railway along Lake Como.

At 500 to 600 volts, allowing from 65 to 75 per cent. efficiency as between the collector and the final utilization of the energy in traction, there is needed from 2½ to 3½ ampères for each effective kilowatt, or say from 2 to 2¾ ampères per effective horse-power. A copper conductor of 0·08 square inch section, which is the size of the ordinary tramway trolley wire, if a current density of 1000 D.C. ampères per square inch be allowed, will thus carry at most 80 ampères, or 30 to 40 effective horse-power. This is only a small fraction of the horse-power needed to work even a short line with heavy traffic upon it. Thus to obtain the required horse-power either the line conductors

would have to be made excessively large, or else the voltage for the transmission of the power must be greatly increased.

8. The full current needed at low voltage must therefore be carried only through short distances. A smaller current at higher voltage is therefore distributed to sub-stations through cables of a combined section which is comparatively small. At each of these sub-stations the energy received is converted and sent out to the working lines at lower voltage. The sub-stations are spaced as evenly as practicable over the whole district to be supplied. Later in this volume will be found explained the economic principles which should limit the extent to which the whole system should be split up into low-tension sections, the limit depending mainly upon relations between the first cost of the sub-stations, the losses in efficiency in the conversions accomplished in these stations, and the gain in efficiency obtained from high-tension instead of low-tension distant transmission.

In some cases the central generating station supplies direct current which is transmitted at high tension to the sub-stations; but in practically all recent installations the current generated at the central power station and transmitted to the sub-station is one or other form of alternating or polyphase current. If this last form of current energy is taken along the line and fed into the car or train motors, then the sole function of the sub-station is to reduce the tension and correspondingly increase the amperage; and this it does by means of what are called "static transformers." It is, however, still the general rule to use continuous or direct current upon the line; and in this case the sub-station has the double duty of transforming from high to low tension, and also of converting from A.C. to D.C. This is accomplished by a combination of "static transformers" and "rotary converters," these latter changing A.C. energy into D.C. energy.

Another important feature of the distribution of energy is the employment of what are called "feeders," which ought not to be confused with the high-tension cables to sub-stations. When no sub-stations are needed as in small tramway systems, still feeders are employed to take current from the central generating station and distribute it to numerous points along the line. Feeders also ramify outwards from each sub-station to numerous points of the section fed from that station.

Normally each section fed by a feeder is insulated from the neighbouring sections on either side; but it is desirable to provide means whereby, in case of breakdown of any feeder and its being cut out for repair of faults or other reason, its section may be fed from the next section, either direct from the line wire or from the feeder of that next section.

The use of feeders to isolated sections does not effect any saving in the necessary sizes of the conductors, nor does it lessen the losses

of energy due to the ohmic resistance of these conductors. But it enables a more nearly uniform working potential difference to be maintained throughout all the sections, an object of great importance for the efficient working of the motors; it obviates the need of large clumsy sections in the line conductors, such as would be impossible upon, at least, overhead lines, whether tramways or railways; and it isolates and localizes the effect of a short circuit or other disturbance of the working that may occur at any one point.

9. We may then sub-classify (B) Tramways according as—

(*a*) Direct current is generated in the central power station at low tension, and transmitted unchanged through feeders and line-sections to the car motors; or

(*b*) Direct current is generated at the central station at high tension, transformed by rotary transformers to low tension at sub-station, and so distributed by feeders; or

(*c*) Alternate or polyphase current is generated at the central station at high or low tension, and converted to low-tension direct current at sub-stations, whence it is distributed by feeders.

Tramways must also be distinguished according to the method of bringing the current along the line to the cars. There are three main systems, namely—

(*d*) The Overhead Trolley, in which a conducting copper wire is stretched in mid-air upon insulators attached to poles erected along the side or down the centre of the roadway.

(*e*) The Conduit Plough, in which a + and a − steel-rail conductor are laid in an underground tube or conduit, this opening to the surface by a continuous slot about ¾ inch wide, through which hangs from the car a "plough" carrying two spring "collecting shoes" (or sliding blocks), to make connection for the passage of the current from and to the conductor-rails through the motor on the car.

(*f*) The Surface Contact or Stud, in which the current is brought to the car through a series of "studs," or metallic blocks, built into the road surface, each of these studs being electrically charged, or "alive," only when a car comes over it, and being left "dead," or disconnected from the supply, as soon as the car has passed over and away from it. The current is collected from the studs by a "skate" slung under the car.

Other systems have been proposed, but as they are not likely to come into practical operation, they need not be mentioned here.

10. (D) Electric Railway systems may be sub-classified similarly as follows:—

(*a*) Short railways in which no converting sub-stations are required, in which case low-tension direct current is nearly certain to be used.

(*b*) High-tension direct current is generated at the central station, and transformed to low-tension direct current at sub-stations, an arrangement offering no advantages, and not likely to be installed in any future railways.

(*c*) High-tension alternating current is generated at the central station, and is transformed and converted to low-tension direct current by static transformers and rotary converters in sub-stations.

In (*a*), (*b*), and (*c*) the motors on the train are all direct-current machines, and in (*c*) the alternating current may be 3-phase, 2-phase, or single-phase.

(*d*) High-tension 3-phase current is generated at the central station, and transformed to low-tension 3-phase at sub-stations, whence the energy is sent through feeders and the line-sections to drive 3-phase synchronous induction motors on the trains. At Valtellina the "low tension" is 3000 volts, and on the line sections there are two copper overhead wires with a duplex trolley collector, the earthed rails serving for the third phase; while the "high tension" is 20,000 volts. In other installations lower voltages are employed. At the Zossen high-speed trials, three overhead copper wires are used with three separate bow collectors to transmit the high-tension current, and the transformers are carried in the car.

(*e*) Single-phase transmission is used with or without transformation from high to low tension at sub-stations, along with single-phase synchronous motors on the trains.

(*f*) Single-phase transmission is used, while the current is "split in phase" in the motor-car, and the resulting 3-phase current is led into and drives 3-phase induction motors.

The systems (*e*) and (*f*) possess the very great advantage of requiring only one conductor, both for transmission and distribution along the line, and only one trolley or other form of collector. They are, however, not so powerful in obtaining quick acceleration in starting, nor so facile in the control of speed.

A further sub-classification of electric railways is based upon the insulation of all the electric conductors involved or the earthing of one of them, and upon the form of the + conductor. Thus—

(*g*) Overhead positive conductors with trolley or bow collectors.

(*h*) Surface-rail positive conductors mounted on insulators spiked or bolted to the sleepers, the rail lying either between the two running-rails, in which case it is called the "mid-rail," or else lying outside these, generally to the left, when it is called an "outside rail," and the collector being a sliding block of iron kept in close contact with the conductor-rail either by its own weight or by spring pressure.

(*i*) The return or negative conductor formed of the two running-rails well bonded together by copper strips and well earthed;

(*k*) With insulated return, sometimes in the form of an overhead suspended wire, but more commonly in that of a "fourth rail" on the surface of the ground, insulated in the same manner as the "out" conductor-rail.

In respect of the mode in which the trains are made up and driven there is the distinction between—

(*l*) Trains made up of passenger cars drawn by one or more electric locomotives, no passengers being carried on the locomotive car; and

(*m*) Trains made up of "motor-cars" which are driven directly by electric motors upon their driving axles, and which carry passengers, associated with "trailer cars" which are not so driven, but which also carry passengers or baggage, or both.

Moreover, electric traction has led to the introduction of certain new mechanical constructions in the forms of railroad. These afford the following extra division of the subject:—

(*n*) Surface railroads of ordinary type with two running-rails.

(*o*) Subways, or tunnels, running immediately under the surface of, and along the axes of, the main heavy-traffic streets of large cities.

(*p*) Tubes, or deep level railroads, from 40 to 100 feet underground, access to, and egress from, which is afforded by lifts.

(*q*) Elevated or overhead railways, with two running-rails per track passing along streets similar to those in (*o*) on a steel bridge-like platform at such height as to leave ample headway under them for all classes of ordinary street traffic.

(*r*) Suspension monorails, in which the cars forming the train hang from an overhead rail, the wheels which run on this rail being mounted over the car-roof in a hook-shaped frame secured by a swivel joint to the car-roof, and the monorail being supported by a bridge-like superstructure carried by piers and cross-girders at suitable longitudinal spans. The most important example of this system is the Langen Monorail Suspension Railway, seen at Elberfeldt, near Düsseldorf, and at Loschwitz, near Dresden. Another method of carrying out the idea is embodied in the "Telpher" lines invented by Professor Fleeming Jenkin, in which the suspension rail is a flexible steel rope stretched between piers, and in which the need of the supporting longitudinal girder is obviated, at the expense, however, of much of the load-carrying capacity, so that the system has been applied only for the conveyance of minerals, etc., at quarries, mines, and similar works.

There has been proposed still another system called the Behr monorail system, on which it has been desired to build a high-speed electric railway between Manchester and Liverpool. It has a single rail to carry the load; but, as it uses four other rails as guides, it

ought rather to be called a five-rail system, and the difficulty of erecting it so as to keep all five rails truly in gauge with each other, and the much greater difficulty of maintaining them in gauge, or, indeed, in maintaining them in position at all along curves traversed at the high speeds proposed for this railway, renders it unlikely that any further description of the system will be called for.

11. Resuming now our classification of the whole subject, it is seen that this may be shortly stated as follows :—

(A)—Common Road Traction, with energy carried on the vehicle in secondary batteries.

(B)—Tramway Traction, with continuous current motors—
- (*a*) With low-tension (L.T.) continuous current (D.C.) generated at central power station.
- (*b*) With high-tension (H.T.) D.C. generated at central station, transformed to L.T.D.C. at sub-stations.
- (*c*) With H.T. or L.T. alternating current (A.C.) generated at central station, transformed to L.T.D.C. at sub-stations.
- (*d*) With overhead trolley-wire transmission of energy.
- (*e*) With conduit plough 2-conductor-rail transmission of energy.
- (*f*) With surface contact, or stud and skate transmission of energy.

(C)—Railway Traction—
- (*a*) With L.T.D.C. generated at central station.
- (*b*) With H.T.D.C. generated at central station, transformed to L.T.D.C. at sub-stations.
- (*c*) With H.T.A.C. generated at central station, transformed to L.T.D.C. at sub-stations.
- (*d*) With H.T. 3-phase current generated at central station, transformed to L.T. 3-phase at sub-stations, and driven by 3-phase asynchronous motors.
- (*e*) With H.T. single-phase transmission and L.T. single-phase synchronous motors.
- (*f*) With H.T. single-phase transmission and L.T. 3-phase asynchronous motors.

. . . .

- (*g*) With overhead line wires and trolley or bow collectors.
- (*h*) With surface positive conductor mid-rails, or outside rails, and gravity or spring sliding-block collectors.
- (*i*) With return or negative conductor by earthed running-rails.
- (*k*) With insulated return or negative conductor, either as a suspended wire or as a fourth rail.

. . . .

(*l*) The train consisting of passenger cars drawn by electric locomotives.

(*m*) The multiple-unit system, in which the train consists of trailer passenger cars drawn in groups by intervening electro-motor-cars which also carry passengers.

. . . .

(*n*) With surface tracks of two rails.

(*o*) With shallow subway tracks of two rails.

(*p*) With deep level tube tracks of two rails.

(*q*) With elevated or overhead tracks of two rails.

(*r*) With overhead suspension monorail tracks.

(D)—Boat Propulsion—

(*a*) Along canals with trolley-wire transmission of energy; and

(*b*) With energy stored on the boat in secondary batteries.

The secondary batteries of (A) and (D) have already been mentioned at some length in this chapter, and these two classes of electric traction are not dealt with further in the present volume.

In the United States of America the distinction between tramways and railroads is not everywhere very sharply maintained. In this country the distinction is likely never to be lost sight of or obscured, although in the future it may be hard to draw any clear line between tramways and electric light railways. If the term "light railway" is preserved, it may be so only for legal purposes. The well-understood distinction between Tramway and Railway is that a tramway runs along public streets and roads over which the public vehicular and pedestrian traffic has free and full right of way; whereas a railway, whether owned by a private company or by a public authority, traverses its own road or ground, to which the public has no right of access unless by permission of, and under the control of, the railway authorities, except at level crossings where the railway authority must arrange for the safe passage of the public. This distinction makes a very large difference in the possibilities of engineering electric design under the one or the other condition.

CHAPTER II

TRAMWAYS

1. General considerations—2. Stone Trams—3. Cable Trams—4. Superiority of Electric Traction—5. Recent Developments—6. Statistical Results—7. Ratio of Single Track to Route Length—8. Number of Cars per Mile—9. Capital Expenditure per Mile—10. Car-mileage per Mile—11. Time Interval between Cars—12. Capital Outlay per Car-mile—13. Passengers per Car-mile—14. Average Length of Trip, Average Fare, Average Number of Passengers in One Car—15. Receipts per Car-mile and per Track-mile—16. Ratio of Revenue to Capital Outlay—17. Working Costs, Depreciation, Interest and Net Profit—18. Distribution of Capital Expenditure—19. Kilowatt Consumption—20. Distribution of Total Costs—21. Uniform Penny Fares for all Distances—22. Table of General and Local Results—23. Diurnal Load Curves—24. Annual Load Curves—25. Normal and Maximum Load Days—26. Maps of Local Tramway Systems—27. Capital and Running Costs of Conduit Trams in London—28. Map of London Trams—29. Surface Contact Trams—30. Comparison of Advantages and Disadvantages of Overhead, Conduit, and Surface Contact Trams—31. Parcel Carriage and Delivery.

1. COACHES for the public service along public roads are a very ancient institution, which flourished particularly well in England despite the wretched construction and upkeep of the highways, these having been always much worse built than in France or in Scotland. On much-frequented routes it was a natural idea to lessen the tractive difficulty by making special smooth, hard, and even tracks for the wheels, a pair of such tracks being laid spaced apart at the common wheel gauge of the majority of the vehicles using the road.

2. Stone tramways have been in use, especially on steep gradients, for centuries, and wooden tramways have long been common in and about quarries and mines. On steep up-grades stone trams are of great helpfulness to horse traction. The system has been revived in 1904 by the London County Council, who have laid such a line up Brixton Hill alongside their new conduit electric tramways, and for the purpose of inducing slow, heavy, up-grade traffic to keep off their electric tram-rails.

The first iron-rail trams in London were so constructed as to be a nuisance to general traffic, and had to be removed. The mistake made was due to unintelligent copying of the central idea of the upright projecting rail of the main railways. If a flat grooved rail

had been used from the outset, the centre of London would have long since been honeycombed with tram-lines. It resulted that it was only forty years ago, and in America, that trams first began their development. The U.S.A. became the field for the solution of the problem, not so much because of the dreadfully bad condition of the roads and streets—because a century ago the roads in England were so bad that nowhere else could they be worse—as because of what may, without material exaggeration, be described as the complete absence of made roads and streets.

3. In ten years' time horse-tramway traction was being superseded by cable traction in San Francisco, which has always been an enterprising city and which suffered from the difficulty of excessively steep grades in some of its streets. It was to overcome this difficulty that mechanical traction by ropes laid in a conduit buried under the street surface was invented. The same difficulty is experienced on the steep hills of the north side of Edinburgh, and here the same solution was adopted some thirty years ago. Twenty-five years later this led to Edinburgh making the mistake of choosing the cable system in preference to electrification, when it was decided to supersede horse traction throughout the whole city by a central-station power system—a mistake that will be hereafter rectified at very great and unnecessary expense. Cable traction on short special lengths of main railways, especially in tunnels, had long been used before its introduction on street tramways—for example, both in Edinburgh and in Glasgow; and still earlier its use in mines was well known.

4. Electric traction in streets has many advantages over the cable. It is less costly, both in construction and in repairs and other working costs; it gives quicker starting and stopping, so that the average speed is much higher in ratio to maximum speed; the maximum speed may be made, without creating trouble, higher than with cable; there is a complete absence of noise when cars are not passing, and when they are passing the noise is quite inconsiderable and is mainly due to the rolling of the wheels on the running rails, on which point all tram systems are alike; there is also much less constructive difficulty at points and crossings. Electric tram cars have been favoured by one adventitious advantage, namely, that they have been introduced at a later period when general car-construction was better understood, and when, therefore, the new cars have been made much more comfortable and cleanlier in the seating and with much easier and smoother spring suspension. This is sometimes claimed as inherent in electric as distinguished from other kinds of traction; but it is evidently due simply to the historic period of its invention and development.

As in all other departments of electric engineering, Britain has lagged badly behind other parts of the civilized world in the spread of electric tramways. As usual, the English were first in the field of

invention and last in that of development. The Siemens light railway at Portrush, in Ireland, was the first laid down anywhere (in 1883); and in 1885 Sir William Siemens, who was a British subject and almost completely an Englishman, exhibited in operation an electric tramway at the Vienna Electric Exhibition. Up till 1890 only 37 miles of track (single) had been completed in Britain and Ireland. In 1895 Bristol added 52 miles of track, covering 29 miles of streets and roads, to the list; and in 1896 Dublin added 92 miles.

5. Since 1896, when the Light Railways Act was passed, progress has been much more rapid. It was not, however, until after 1898 that extensions began to be rapidly pushed. From 1894 to 1898 the capital expended on tramways in the United Kingdom increased from 14 to only 16 millions sterling; but between 1898 and 1902 went up to $31\frac{1}{2}$, and in 1903 to $41\frac{1}{2}$ millions. This extension is almost wholly due to the introduction of electric traction.

The largest additions have been 130 miles in Glasgow in 1898; 103 miles in Liverpool in the same year; 62 miles in Sheffield in 1899; and 135 miles in Manchester in 1901.

In this year (1901) the London United Tramways Co. opened 58 miles of track along 30 miles of road, stretching westwards from the Shepherd's Bush terminus of the Central London Tube Railway to Ealing, Brentford, and Kew.

London proper began only in 1903, when she completed 16 miles single track, or 9 miles of road, of the electrification of her southern tramways, and by August of 1904 had opened in all 26 miles of road, or nearly 52 miles of single track.

Between 1898 and 1902 the length of tramways open for traffic increased from about 1000 to 1500 route miles; and by midsummer, 1903, to 1772, of which 60 per cent. are owned by local public authorities. Of these 70 per cent. were using electric traction, and this proportion is now considerably greater.

6. There are now nearly 2500 miles of single track at work along 1500 miles of road; other 1000 miles track are being constructed, and other 2000 miles are authorized. Thus very shortly there will be some 5500 miles of electric track in operation in the United Kingdom.

7. On the lines already opened, the ratio of length of single track to length of road is 1·6; but this ratio will diminish in the future, because most of the existing lines are for dense traffic, where double track is a necessity throughout. A larger proportion of future extensions will be in outlying suburban or country districts, where much of the road length will be served by single-track lines. Thus on the 5500 miles above referred to, the ratio is expected to be about 1·45, the length of roadway served being 3800 miles.

8. The number of motor and trailer-cars on the working lines is nearly 3·2 per mile of single track, or 5 per mile of roadway served.

For dense city traffic, however, 10 cars per mile of roadway are needed.

Within two or three years some 20,000 electric motor tramcars will be in use in the kingdom, assisted by some 400 or 500 trailer-cars.

9. Over £80,000,000 capital is already expended or subscribed in these tramway enterprises. If this were distributed over the 3500 miles now running and under construction, it would give £23,000 as the total cost of each mile of single track. Much of it, however, is devoted to the lines now being promoted, and part of it is not yet spent; so that £15,000 is probably near the actual capital cost of an average mile of single track. This includes expenses of promotion, buildings, power plant, and cars, as well as the road itself. At midsummer, 1903, this average was £14,350 over all horse, cable, and electric trams in the kingdom.

An average obtained from about 1000 electric working miles scattered fairly over the country gives £14,500 per single mile; but among these lines there are immense differences, one, namely Ayr, apparently building trams at £9000 cost, while four of them cost £20,000, £22,000, £23,000, and £24,000 per single mile, and in many places the cost is £16,000 to £18,000. From the latest report, the Glasgow lines have cost £19,000, and Newcastle-on-Tyne £23,000.

As most of these lines are old lines converted to electric traction, the average for new electric lines is over the above £15,000, and probably may be taken at £17,000.

10. From a large number of returns from lines of various degrees of activity, the writer calculates that the average yearly number of miles run by the cars, or the "car-mileage," is about 73,000 per mile of single track. This is the best measure of the activity of the line, but it is not a calculation found in the engineers' reports. From the Board of Trade returns it was in 1902–3 64,000 miles over all tramways, horse, cable, and electric, in the kingdom. It varies greatly, being as much as 120,000 in the network of some large cities. In Glasgow it was, in the year 1903–4, 116,000 per year = 318 per day of 16 hours normal running = nearly 20 per hour = 1 per 3 minutes. This represents an average "3 minutes' service," *i.e.* the cars follow each other at an average time interval of 3 minutes. At mean speed 8 miles per hour, this gives an average space interval between successive cars of $8 \times \frac{3}{60} = \frac{4}{10}$ mile = about 700 yards. During the stoppage of a car, the following car approaches it within this normal spacing proportionately to the length of stoppage; if the stoppage be $\frac{1}{5}$ the normal time interval, the distance is reduced to $\frac{4}{5}$ the normal spacing. The irregularities of running, *i.e.* the losses and gains on "schedule time," cause much closer approach of the cars than normal stoppages, the effects of such irregularities having a tendency to become cumulative.

11. Since 365 16-hour days contain 350,400 minutes, it is useful to remember that a 1-minute service maintained steadily for a year at 16 hours per day would yield 350,000 car-miles per mile of single track. If 350,000 be divided by the actual annual car-miles run per mile of single track, the quotient gives the average time interval between the cars. This is so whatever be the mean speed. Thus the average mentioned above of 73,000 car-miles per mile, means an average $\frac{350}{73} = 4{\cdot}8$ minutes' service, and 5 minutes may be taken as the mean over the majority of British tramways.

This number of car-miles per mile, which is thus seen to be inversely proportional to the time interval between cars, is clearly the number of times per year that each part of the road is used. It is therefore one of the most important elements in the economy of the tramway as an industrial concern.

12. The total capital outlay on tramway service in proportion to the yearly car-miles run ranges from 3*s.* 6*d.* to over 5*s.* per car-mile, and averages over 4*s.*, or say 50 pence.

13. But the activity of revenue collection from the line will also depend upon how many passengers are carried per car. The number of passengers carried per car-mile run is the figure most often calculated and quoted to show how much the cars are used. On the 1000 miles already referred to the average passengers per car-mile is 10. On the Glasgow lines, which are included in these 1000 miles, the average is 11½. On some lines it is as low as 4, and on some as high as 15. In Glasgow it was 13 in 1901–2, and the decrease is due to extensions in outlying districts on which the traffic will not be fully developed for some years yet. When it is fully developed, the number will again go probably above 13, provided further large extensions into sparsely inhabited districts have not in the mean time been added to the system. Over all the trams in the kingdom in 1902–3 the average was 9·4.

14. But this number is an unsafe index of activity, because any single passenger may ride ½ mile or 2 or 3 miles. If every passenger rode on the average 1 mile, then the above quotient would be the mean number of passengers in each car at all times. But if every one travelled on each trip 2 miles, then this would double the mean number in each car continuously. The only way to find the average distance travelled by a passenger is to compare the average fare paid with the average charge per mile. The former is easily ascertained, because the total passenger traffic receipts and the total tickets sold are both strictly recorded. On our 1000 miles the average fare paid per ticket is 1·06*d.* In Glasgow in 1903–4 it was 0·9*d.*, and probably 1*d.* may be taken as a fair general average. The average charge per mile depends greatly on the scale of fares, which is always more per mile for short than for long distances, but which

has great local variations according to the policy adopted locally to encourage traffic. We fear that in the managers' reports the "average fare charged per mile" is usually calculated on an erroneous basis, namely, from a consideration solely of the stage lengths allowed by the scale for the different priced tickets, and without giving any weight to the numbers of passengers travelling each stage length. In this way 0·45*d.* is calculated as the average fare per mile in Glasgow; and dividing the average fare per passenger, namely, 0·9*d.*, by this, we obtain 2 miles as the average length of trip per passenger. The true method of finding the average charge per mile is to take from the scale the stage length corresponding to the average price paid per ticket, and compare this price with the length thus taken from the scale; because this is evidently the stage length allowed on the average to each passenger. Some allowance ought properly to be made for the average passenger not travelling the full length his ticket permits him to travel. In Glasgow the full length corresponding to the average fare would be in 1903–4 just under 2·1 miles, and this would be at the rate of 0·43*d.* per mile.

15. If the average length of journey in British tramways be taken as 2 miles and the passengers per car-mile as 10, it follows that 20 passengers is the average number constantly riding in each car. And if the mean charge for this 2-mile trip be assumed as 1*d.*, then 10*d.* per car-mile run will be the average passenger traffic revenue. This is the same as £1000 for every 24,000 car-miles run. From the most recent available statistics, 10½*d.* per car-mile is the average passenger revenue on the fairly prosperous lines. In Glasgow it was 10·6*d.*; in Liverpool, 10·3; in Nottingham, 12·9; in Leeds, 10·9; in Dundee, 10·9; in Dublin, 8·6; in Sheffield, 10·4.

It has already been stated that the mean annual car-miles run per mile of single track is 73,000. Taking this at £1000 per 24,000 car-miles, there is obtained an average annual traffic revenue of £3040 per mile of single track, or rather over £6000 per mile of double track. The actual average in 1902–3 on the 1000 miles already quoted was £3200; but it was probably somewhat less in the following year. This ratio naturally varies enormously according to the density of the traffic. It is in some cases as little as £1000; often £1300 to £1500; in many large busy places no more than £2500 to £3000; and in very few over £4000. In Glasgow it was £5130 in 1903-4 on the newly extended system, and in Liverpool it is also about £5000.

The most accurate measure of the traffic density is the number of passengers carried per year per mile of single track. In 1902–3 on all the tramways of the kingdom this density was 603,000.

16. On these 1000 miles the ratio of annual traffic income to capital outlay is 22 per cent. On all the tramways in the kingdom it was in 1902–3 only 19½ per cent. On lines of denser traffic it is

higher; for instance, on the Glasgow network it is 26½ per cent. This is a ratio of the greatest financial importance. It indicates the rapidity of "turn-over" of capital laid out, and this is one of the chief factors in economic working. The 22 per cent. ratio means a turn-over once in 4½ years; the 27 per cent. ratio once in 3·7 years. Some fortunate industries have a complete turn-over of all the invested capital in little more than half a year, and a considerable number in from 1 to 1½ years. Land transportation of all kinds is fairly low down in the scale, but ordinary steam railways are much worse off than tramways in this respect. British railways on the average have a gross revenue of only 10 per cent. of their capital, while water-supply companies get still less, and the average electric-lighting company no more than 12 per cent. Coal-mining yields 25 to 100 per cent.; general mechanical engineering, 60 to 70 per cent.; iron and steel making, 100 per cent.; the shipping trade, 90 to 100 per cent.; cloth manufacture, 150 per cent.; and ship-building, 175 per cent. Electric tramways, although well removed from the bottom of this scale, stand a long way below the more fortunate trades. It must be understood that the slower the rate of turn-over the higher must be the ratio of profit per unit of value produced in order to make the annual rate of profit a reasonably acceptable one—that is, the higher must be the ratio of gross receipts to total working costs.

In tramways owned by companies about half the invested capital is in the form of debentures and preference shares, upon which averages of 4½ and 5 per cent. are paid as interest and dividend. These two together thus absorb about 2¼ per cent. out of the 22 per cent. gross revenue, leaving under 19¾ per cent. to cover working costs, depreciation, sinking and reserve funds, and profit or dividend on the remaining half of the capital.

Tramways owned by public authorities are constructed by moneys borrowed at an average rate of 3 per cent. interest.

17. The working costs of electric tramways are sometimes as low as 50 per cent. of the gross revenue, and sometimes as high as 75. They average exactly 60 per cent. This average has varied very little for many years past, and it is curiously constant in different countries. With horse and cable trams the ratio is much higher; and in 1902–3 the average over all the trams in Britain and Ireland was 68 per cent.

Sixty per cent. of 22 per cent. equals 13¼ per cent.; and 13¼ deducted from 19¾ leaves 6½ per cent. to cover depreciation, reserve funds, and profit on the ordinary shares of companies. They generally pay between 4 and 5 per cent. dividend. Taking the dividend at 4½, which is well above the real average, this absorbs 2¼ per cent., as it is paid on one-half only of the capital. Thus 4¼ per cent. remains to provide for reserves and depreciation. This explains why less than 3 per cent. is now being written off per year as depreciation.

Since the average dividend on ordinary capital is about the same as the average rate paid on debentures and preference shares, the calculation may be otherwise put thus; working costs 13¼ plus interest and dividend on capital outlay 4½ gives 17¾ to be deducted from the 22 per cent. gross revenue, leaving 4¼ for depreciation and reserves.

These proportions are slightly modified if one considers the municipal undertakings separately from the private companies. In the former the average ratio of working costs to revenue is the same as in the general total, namely, 60 per cent.; but the ratio of revenue to capital is rather more favourable, namely, 24 per cent. Sixty per cent. of 24 per cent. equals 14½ per cent., to which is to be added only 3 per cent. interest on capital, making together 17½ to be deducted from 24. This leaves 6½ per cent. to provide for depreciation and sinking funds, and to pay something towards the relief of local rates. Although in many cases no such relief can as yet be paid, still in the better positions of the stronger municipalities a very substantial sum is yearly paid over to the "common good."

In Glasgow the revenue is 26½ per cent. of the capital outlay, and the working costs, exclusive of depreciation and renewal fund for the permanent way, is 50 per cent. of the revenue, or 13¼ per cent. of the capital. With 3 per cent. interest added to 13¼, there is left over from the revenue 10¼ per cent. to cover depreciation, etc. This has been devoted to writing off 2·9 per cent. "ordinary" and 2·3 per cent. "special" depreciation, or 5·2 per cent. in all; to a "permanent-way renewal fund," at the rate of £450 per single mile; to a "payment to the common good" of £25,000; and to the general reserve fund.

18. The capital outlay, exclusive of parliamentary and other similar preliminary expenses, is made up somewhat in the following proportions:—

TABLE III.

Ground and buildings		20 per cent.
Permanent way	30	
Electrical equipment of ditto	20	
	—	50 "
Cars	8	
Electrical equipment of ditto	7	
	—	15 "
Plant in power station, sub-stations, and workshops		15 "
Total ...		100

The proper amount of "depreciation" to allow on this depends very largely upon how thoroughly repairs and maintenance are kept up, and how much of the cost of these is charged to accounts separate from depreciation. The following may be taken as the lower and upper limits of reasonable requirements:—

TABLE IV.—DEPRECIATION.

	Lower limit.	Upper limit.
Ground and Buildings	$20\% \times 1\frac{1}{2}\% = 0{\cdot}3\%$	$20\% \times 3\% = 0{\cdot}6\%$
Permanent Way, Electrical Equipment of ditto	$50\% \times 3\% = 1{\cdot}5\%$	$50\% \times 6\% = 3{\cdot}0\%$
Cars, Electrical Equipment of ditto, Station Plants and Workshop, Tools, etc.	$30\% \times 6\% = 1{\cdot}8\%$	$30\% \times 8\% = 2{\cdot}4\%$
Percentage on total	3·6	6·0

Taking 50*d*. as the mean capital invested per annual car-mile, and 5 per cent. depreciation plus 3 per cent. interest as average capital charges (exclusive of sinking funds), these will amount to 4*d*. per car-mile run.

19. The average consumption of energy in driving the cars varies in different places from 0·8 to 1·4 B.T. Units per car-mile, according to the size of the car, the density of the traffic, and other conditions. Within any one network it varies greatly, of course, according to the gradient, curves, etc. The average on our 1000 typical miles is 1·28; but it ought to be not much over 1 B.T. Unit. The cost of this per unit depends much upon whether the system is large enough to justify the erection of a special power station. If the power be bought from an outside supply company, generally over 2*d*. per unit is paid for it, while if the tramway authority has its own central station, the cost entered in the accounts is usually well below 1*d*. The real difference is, however, not nearly so large as it seems, because in the latter case neither the capital charges due to buildings, nor the repairs and depreciation of the power plant, are entered in the "power" account. If the repairs were added in their rational place, this addition would increase the cost by some 50 per cent.; while, if the depreciation and capital charges due to the power station and plant were

also included, the cost would be raised in the ratio 2½ or 3. Thus the Glasgow accounts show the cost per B.T. Unit as 0·31*d.*, whereas if repairs were added it would be about 0·43*d.*; and, if the due share of depreciation and capital charges were also added, it would be 0·87*d.* As against this may be cited the case of the Liverpool tramways, which buy energy at 1¼*d.* per unit. But this purchase price is unusually low, firstly, because the amount purchased is very large—larger than the total used in Glasgow—and secondly, because it is bought from the corporation's own electric lighting station.

20. The amount of power used is of great technical interest; but it is of minor commercial importance, its cost being almost swamped by the magnitude of the other expenses not amenable to scientific engineering minimization. The following table shows approximately how the cost of running one car over one mile is made up:—

TABLE V.—TOTAL COST PER CAR-MILE.

Working costs, 5½*d.*	Power	½	pence
	Traffic expenses	3	„
	General expenses	1	„
	Plant repairs and maintenance ...	1	„
Capital charges, 4½*d.*	Roadway maintenance and renewal	½	„
	Depreciation at 5 per cent.	2½	„
	Interest at 3 per cent.	1½	„
	Total	10	pence

If the division between working and capital costs indicated in this table be adopted, it makes these respectively 55 and 45 per cent. of the total. This estimate is fairly comparable with the 10½*d.* per car-mile gross traffic receipts previously given as the average on 1000 miles of successful lines. According to it 5 per cent. of the total receipts is available as net profit or dividend, or payment in relief of rates, etc., over and above 3 per cent. interest on capital. This 5 per cent. of the receipts is equivalent, however, to only 1 per cent. on the capital invested.

Although many minor installations may do worse than this, the above is a conservative view of the capabilities of British electric tramways, and it may be confidently reckoned that skilful and energetic management will always be able to show somewhat better results. Under the more fortunate conditions considerably better results can, and are actually, obtained.

But it must be noted that only 5 per cent. is spent on power production, while "traffic" and "general" expenses absorb together 40 per cent. Repairs, upkeep, and depreciation are responsible for another 40 per cent. In the 3*d.* "traffic" expenses, about 2½*d.* goes in payment

of wages of drivers, conductors, and other servants. This cannot be reduced except by doing away with the conductor, and introducing automatic sale and collection of tickets; and this is evidently impossible unless the English system of short ½*d.* stages be abandoned.

21. As two-thirds of the traffic receipts are collected in the form of 1*d.* fares, and only one-sixth in the form of fares more than 1*d.*, it appears that no real loss of net revenue would result from charging one uniform fare of 1*d.* for all distances from or towards certain main centres or terminii, where each car would be cleared of passengers. Such a system makes it possible that a slot machine should take the place of the conductor for collection of fares, and this would probably reduce the traffic expenses by about 1*d.* per car-mile. The "general" expenses are incapable of the like drastic reform, but they are no doubt reducible in some substantial degree. The "repairs" and "depreciation" go together; if the money spent on repairs be cut down, the real depreciation (whatever may appear in the published accounts) infallibly goes up. The sum of the two, however, can be, and no doubt will be, gradually diminished by improvements in the design of the plant not involving large extra capital outlay.

Table VI. gives the author's calculation of the expenditure upon all the tramways of the kingdom during the year 1902–3, reduced to per car-mile by dividing by the total car-miles run. This division is irrational as regards the power expended as separated into horse and mechanical power; so that these two must be added to obtain the mean. As the cost of animal power in that year nearly equalled that of the mechanical power, while the length of line worked by horses was only 18 per cent. of the total, it will be understood how seriously the inclusion of this item raises the average. The abolition of horse traction and its substitution by mechanical power (leaving all other items unchanged) would reduce the total of 7·4*d.* to 6·7*d.* The author's independent estimate given in Table V. is 6*d.* to cover the same items.

TABLE VI.—EXPENDITURE PER CAR-MILE FROM 1902–3 BOARD OF TRADE RETURNS OF ALL TRAMWAYS AND LIGHT RAILWAYS.

	Pence.	
Maintenance of Way and Works	0·56	
Locomotive and Electric Power	1·03	1·98
Animal Power	0·95	
Repairs and Renewals Engines	0·09	0·20
Ditto Horses	0·11	
Ditto Cars	0·52	
Traffic expenses	2·99	
Direction and Management	0·22	
Rents, Rates, Taxes, and Sundries	0·93	
Total	7·40	

[O]verhead British Tramway Systems.

Annual traffic revenue per car.	Passengers per car-mile.	Traffic revenue per car-mile.	Working costs per car-mile.	Energy consumption per car-mile. Board of Trade units.	Ratio of annual revenue to capital outlay.	Ratio of working costs to revenue.	Ratio of annual working costs to capital outlay.	Ratio of annual excess of revenue over working costs to capital outlay.	Ratio of net profit to capital after deducting 3 per cent depreciation, sinking fund, and interest.
Unit 1000. 11.	12.	d. 13.	d. 14.	B.T.U. 15.	Per cent. 16.	Per cent 17.	Per cent. 18.	Per cent. 19.	Per cent. 20.
1	**10**	**10·5**	**6·2**	**1·28**	**22**	**60**	**13·2**	**8·3**	**0·8**
1·03	11·5	10·6	5·2	0·94	26·5	50	13·2	13·3	5·3
1·00	8·5	9·5	5·4	0·87	25·5	57	14·5	11·0	3·0
1·08	9·5	10·7	7·0	1·53	28·5	64	18·2	10·3	2·3
1·1	10·0	11·0	6·6	1·3	26·2	61	16·0	10·2	2·2
1·22	11·1	12·2	6·8	1·37	22·5	56·6	12·6	9·9	1·9
0·87	9·6	9·6	6·1	1·26	26·4	63·2	16·6	9·8	1·8
0·73	12·6	12·5	6·8	1·05	19·4	54	10·6	8·8	0·8
0·85	9·5	9·8	5·1	1·00	18·3	52	9·5	8·8	0·8
1·06	8·6	10·9	7·7	1·13	26·1	70·7	18·5	7·6	—
0·91	7·3	9·3	5·0	1·57	15·5	54·1	8·4	7·1	—
0·87	7·1	8·6	5·4	1·06	14·5	55	8·0	6·5	—
1·08	9·8	10·7	7·2	1·91	17·1	67·3	11·5	5·6	—
0·75	12·0	12·0	9·05	1·80	19·5	75	14·7	4·8	—

To face p. 35.

22. The following Table VII. gives results, similar to those discussed above, calculated from the published statistics of thirteen overhead tramway systems, large and small, with dense and sparse traffic. Along the top line are given the averages on the previously mentioned 1000 miles of successful line chosen as typical of British conditions. The vertical columns give the results reduced to per mile of single track, to per car in use, and to per car-mile run, as well as their reduction to per cent. of the capital expenditure: there being in all twenty columns of reduced results. It shows how much deviation may be expected under particular conditions from the averages already given.

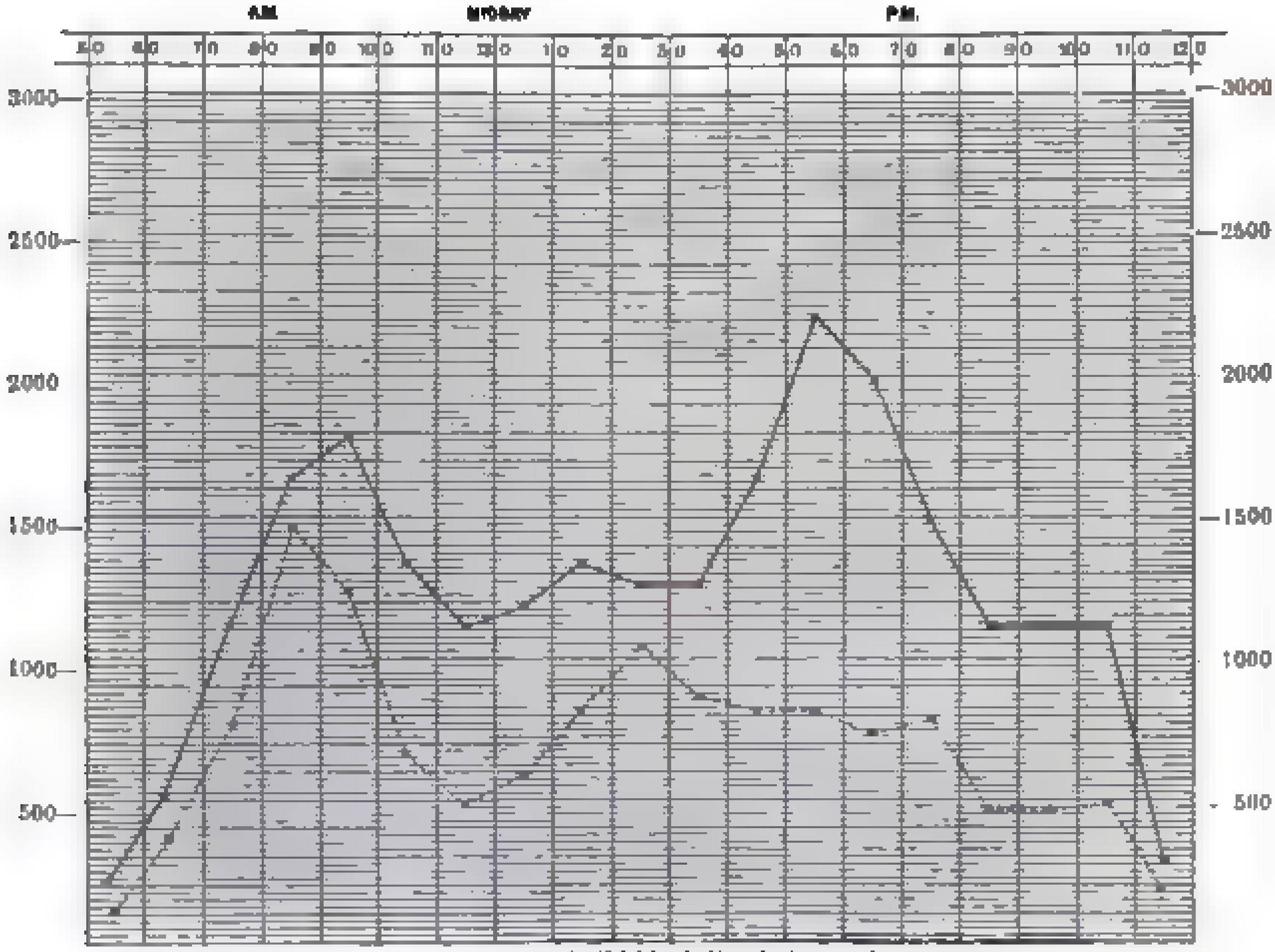
23. It was shown above that the average number of passengers at any one time in a single car is about 20, and in dense traffic, such as is found in Glasgow, 23. This average is low because of the need of putting cars on the road sufficient to cope with the heaviest demand. So far as this demand changes regularly and slowly, its changes may be followed by a wide-awake manager by correspondingly varying the number of cars sent out per hour. But it also varies very erratically and suddenly. Thus in Liverpool during the morning and evening busiest hours the number in each car varies irregularly between 30 and 74, the latter number being the full sitting and standing licensed capacity. Thus the supply of seating accommodation at all hours must perforce far exceed the average demand at the same hour.

Again, at each of the two daily periods of maximum traffic, the bulk of the traffic is in one direction. In the morning it is in towards the centre of the dense population or of the business quarter; and in the evening it is outwards. At each of these times, in order to carry the crowd in one direction, almost empty cars must be sent in the opposite direction; they are sent outwards to serve the inward traffic, and *vice versâ.*

This is finely illustrated by the two diagrams (Figs. 6 and 7) prepared by Mr. C. R. Bellamy, general manager of the Liverpool Corporation Tramways, for his annual report at the end of 1903. Here the full line indicates the full licensed capacity of the total cars running on one main route at each hour of the day, while the dotted line gives the actual number of passengers carried. In Fig. 6 the peak of the maximum demand for the inward traffic is between 8 and 9 a.m. Up till 3 p.m. the supply, as indicated by the full black line, is skilfully made to follow the demand very closely with the percentage of over-capacity, averaging some 50 per cent., made necessary by sudden erratic variations. But in the afternoon up till 8 p.m., there is no such correspondence between the full and dotted lines. Turning to Fig. 7, which refers to outward traffic, we find that from 3 p.m. to 11 p.m. the full black supply curve is made to follow

LIVERPOOL.

Diagram indicating the Licensed Capacity of the Cars running over a Typical Route on the Inward Journey during each hour of a traffic day and the number of Passengers actually carried. (Midwinter.)



Solid black line indicates licensed capacity.
Broken black line indicates actual passengers carried.

Fig. 6.

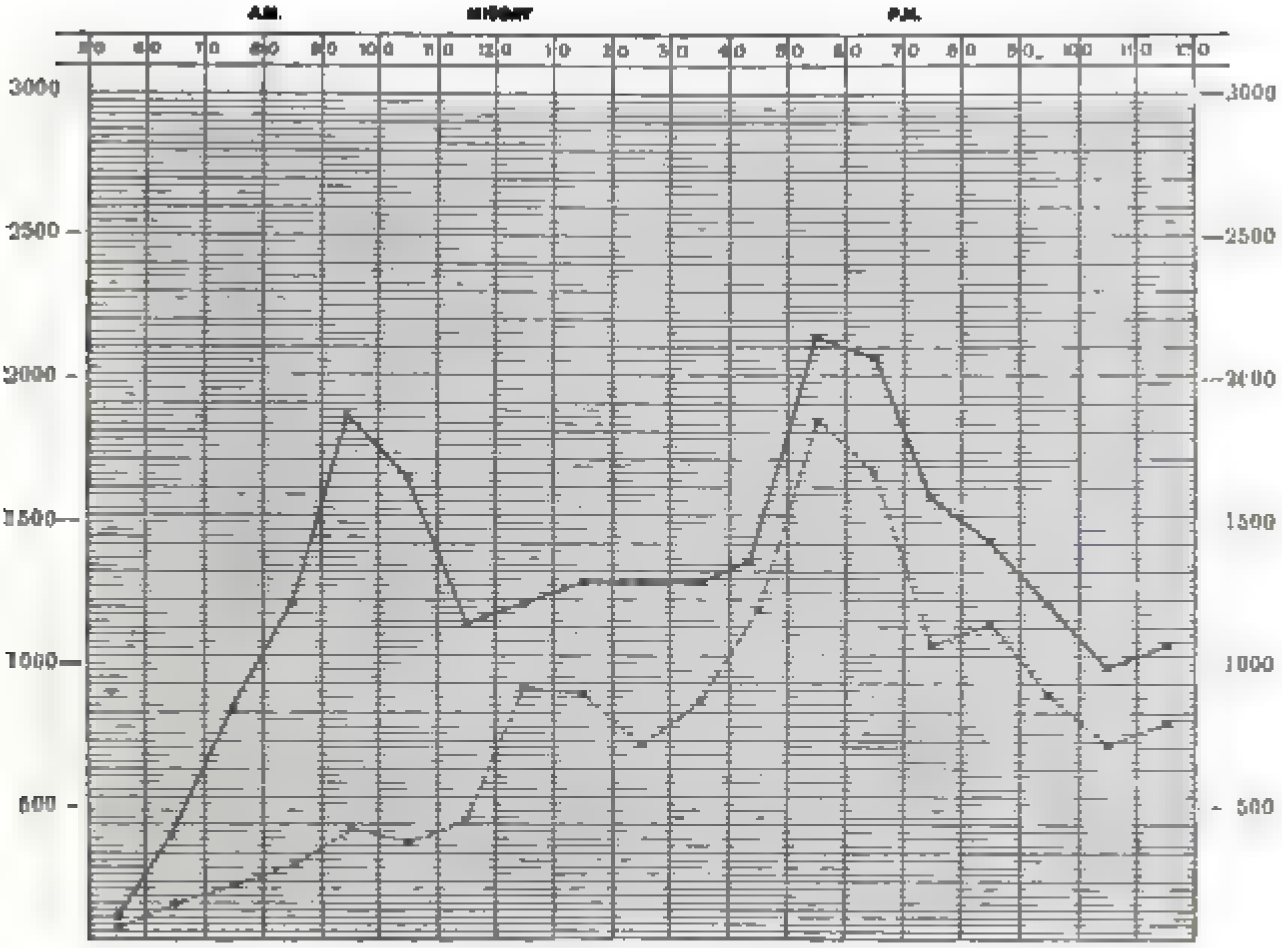
closely the dotted demand curve; but no correspondence between the two appears during the morning hours. In fact, the afternoon full curve of Fig. 6 fits the afternoon dotted curve of Fig. 7; and the morning full curve of Fig. 7 fits the morning dotted curve of Fig. 6.

Measured in passengers per hour these diagrams together show a morning peak-load about 50 per cent. greater than the midday load, while the evening peak is about 75 per cent. greater than the same.

24. Fig. 8 is also an interesting diagram taken from the same report by Mr. Bellamy. It shows the variation of traffic month by month for several years. In 1897 there was no electric traction in the city. In the following year the first beginnings of the new system came into operation. In the middle of 1903 horse traction was finally completely superseded. In each of the year's curves there is a rapid rise from February to June. This must not, however, be wholly attributed to the change of season. Of the rise of from 2½ to 3 million

LIVERPOOL.

Diagram indicating the Licensed Capacity of the Cars running over a Typical Route on the Outward Journey during each hour of a traffic day and the number of Passengers actually carried. (Midwinter.)



Solid black line indicates licensed capacity.
Broken black line indicates actual passengers carried.

FIG. 7.

passengers from the middle of February to midsummer, over half a million is accounted for by annual increase. Deducting this, the seasonal variation of either minimum or maximum from the yearly mean was about 10 per cent. of that mean in 1903; 18 in 1902; and 15 in 1901. The oblique straight lines in the diagram indicate the mean rate of continuous increase. It should be noted that this was very slow in 1897 and 1898 before the commencement of electric traction; that it became very rapid during the three years occupied in substituting electric for horse traction; and that it is now again not so great.

In Glasgow no seasonal variation of the traffic that is at all regular can be discovered from examination of the statistics.

25. In Leeds the tramway kilowatt load upon the central generating station rises gradually from 5 a.m. to 8 a.m., and remains remarkably steady from 8 a.m. until late in the evening, the load being sometimes maintained nearly constant until 10.30 p.m., and sometimes commencing to fall off somewhat as early as 8 p.m. Fig. 9 gives the two

autographic records of voltage and of ampères consumption during the 27th July (a Wednesday) of 1904. The voltage is kept at a very steady average of 525. The momentary fluctuations are due to the heavy flux of current when several cars happen to start at the same time. This momentary fluctuation is generally between the limits 510 and 540, each swing from minimum to maximum seldom exceeding 20 volts. The extreme low limit is 495 and the extreme top limit 545; but the extreme range of one swing may be taken as 30. The consumption between 8 a.m. and 4 p.m., and between 8 p.m. and 11 p.m., is about 3000 ampères; and in the afternoon, after 4 p.m., it rises to 3800 ampères. The maximum momentary consumption is 4800 ampères. The average range of momentary variation is from 600 to 800 ampères, and the maximum swing is about 1500 ampères.

Fig. 10 gives similar records from the Leeds generating station for Bank Holiday, August 1, 1904. The voltage was increased to

LIVERPOOL.

DIAGRAM SHOWING PASSENGERS CARRIED PER MONTH DURING THE YEARS 1897, 1898, 1899, 1900, 1901, 1902, AND 1903.

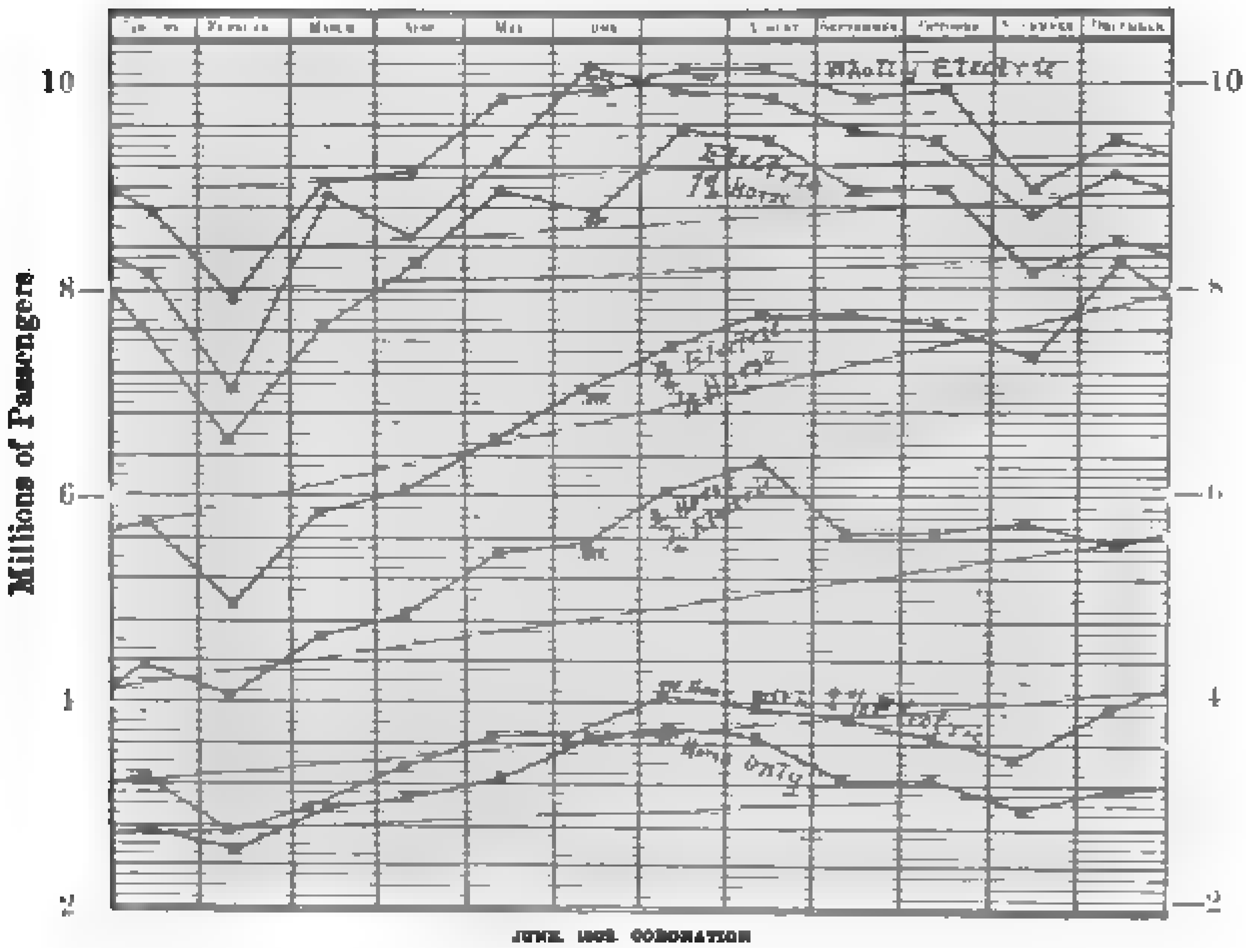


Fig. 8.

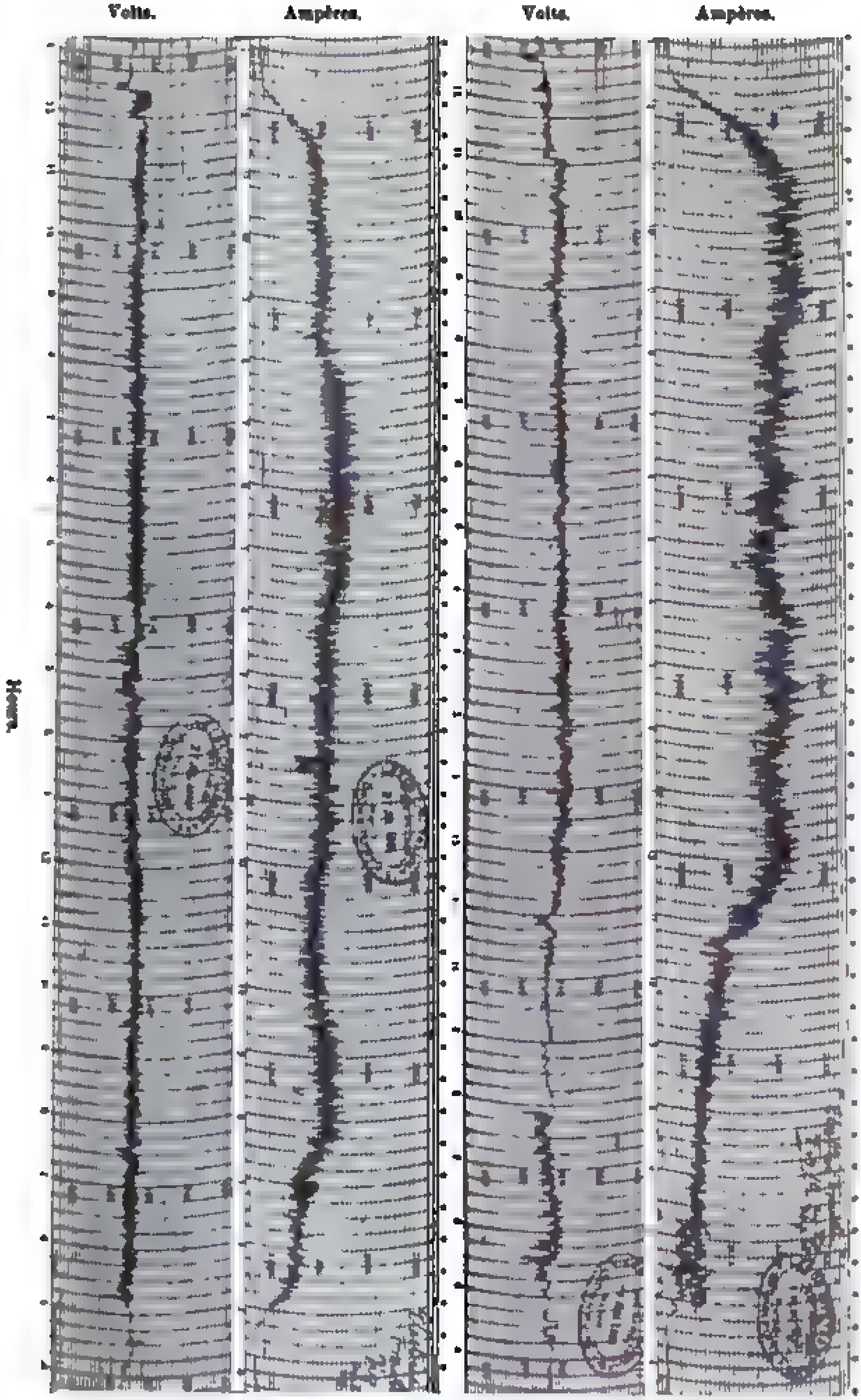


Fig. 9.   Fig. 10.

550 from 11 a.m. to 11 p.m. The energy consumption rose from

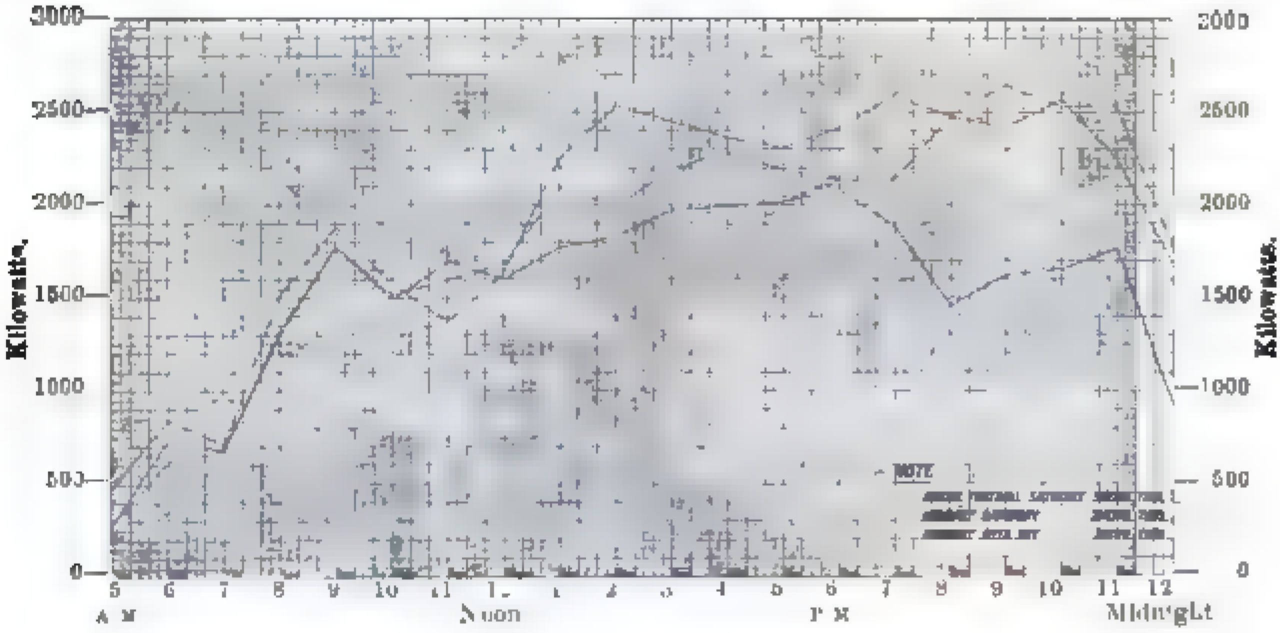


FIG. 11.—Diurnal Diagram of Kilowatts in Glasgow.

1500 ampères at 5.30 a.m. to 3000 ampères at 11 a.m., and to 5000 at midday. From midday to 11 p.m. it remained at an

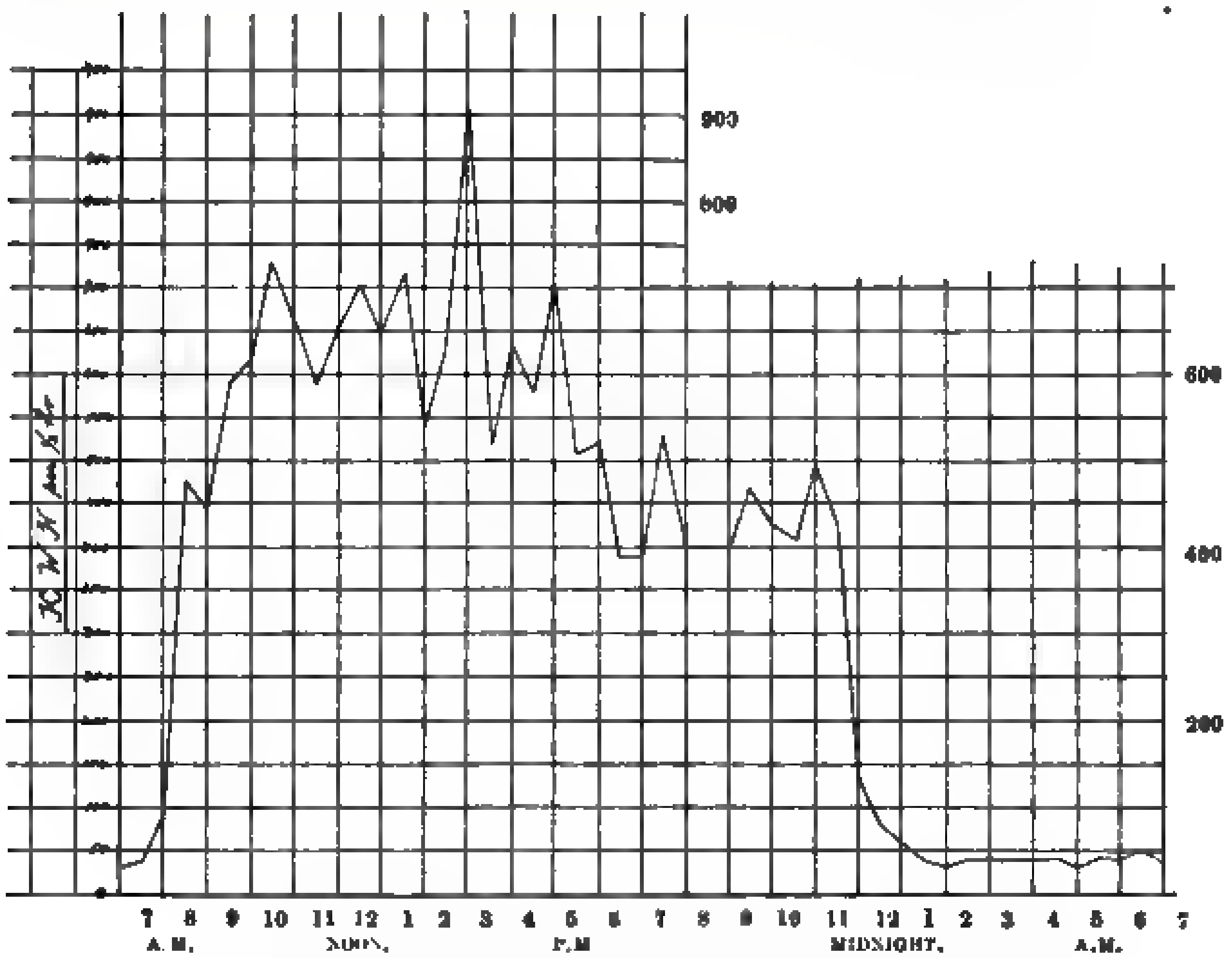
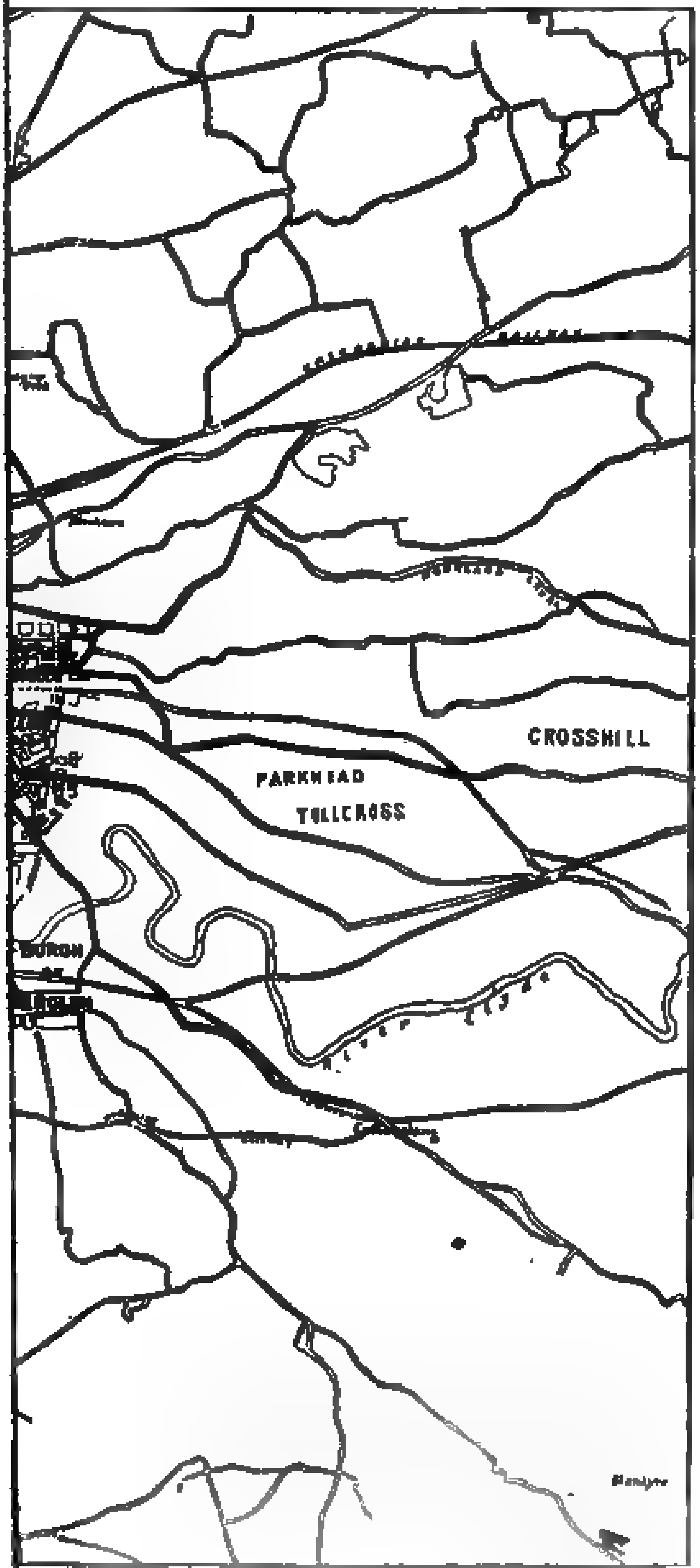


FIG. 12.—Diurnal Kilowatt Diagram, from Dublin United Tramways Co., Ringsend Power Station, Friday, 19th August, 1904.



gle track, 135. [*To face* p. 41.

average of 5000, occasionally going up to 5500, and between 9 and 10 p.m. to near 6000, with momentary excursions to close upon 7000. The oscillations are naturally more violent than on an ordinary day, reaching frequently a range of 1800 ampères.

Fig. 11 gives three similar diurnal diagrams, showing the kilowatt consumption from the Glasgow Tramway Central Power Station. The top curve is for a "special football Saturday;" the middle one for an "ordinary Saturday;" and the lower curve for an "ordinary week-day."

Fig. 12 is a normal kilowatt diagram showing the variation over one day in the Ringsend Power Station of the Dublin United Tramways Co. Here the ordinates are "K.W. hours per ½ hour," and the readings must be doubled to convert them to kilowatts.

26. In Figs. 13, 14, 15, and 16 are given small scale maps showing the tramway systems of Glasgow, Liverpool, Leeds, and Dublin, as completed and at work electrically at the end of the year 1904. To these are appended notes of the area of population served, and the length of tramways and number of cars serving them. These four places, among those at present equipped electrically in Britain, are the most typical of well-populated districts. The other most important completed installations are in much more scattered situations.

27. The figures already given all refer to tramways constructed on the overhead trolley system with 500–550 volt continuous current. The conduit system has been in operation for many years in Buda Pesth, and for several in New York and Paris. In Britain, Blackpool, Bournemouth, and London are as yet the only places where it is illustrated. In London its installation may be said to have been only just begun, and it is at present confined to London south of the Thames. Towards the end of 1904 there have been completed 54½ miles of single track. In a paper read by Mr. A. Millar before the Institution of Civil Engineers in January, 1904, the cost of the permanent way and its electrical equipment is stated to have been £15,900 per mile single track, which includes £458 for the removal of pipes and other obstructions. This latter must always be a serious item in the cost in places like London, and it has probably actually cost the contractor considerably in excess of the sum allowed him under this head. Including buildings, plant, and cars in the ratio of 6·1 cars per single mile, Mr. Millar's paper gives the total cost as £25,100 per single mile. These figures refer to the first 16½ miles (single) that were constructed. The London County Council Tramways accounts closed on March 31, 1904, refer to the construction of 45 miles then completed, although not all then running electrically.[1] These accounts make the total capital expenditure

[1] Before the accounts were published, the Streatham line was opened on August 2, but this length is not included in the here-mentioned 45 miles.

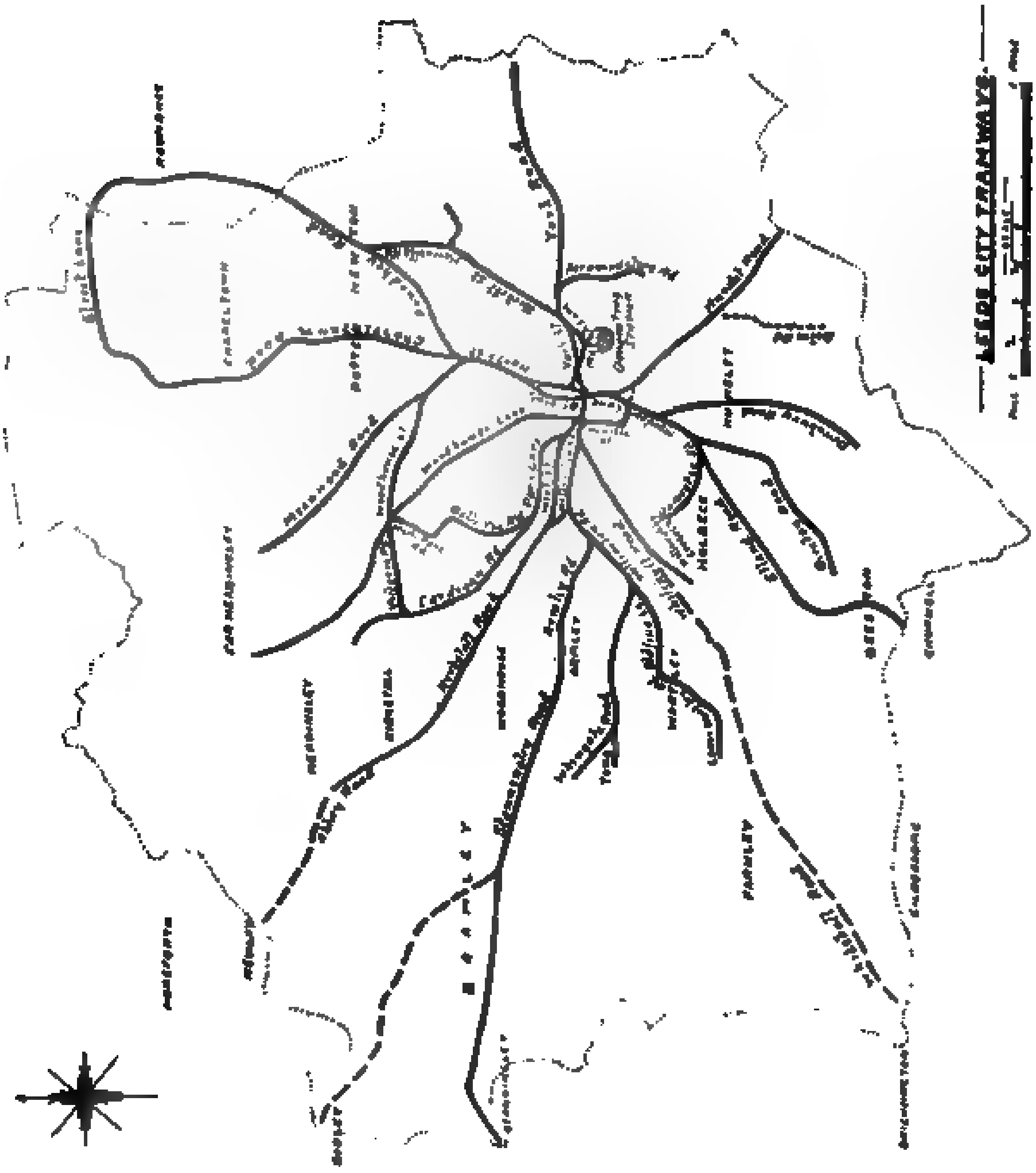
Limits of area served, 9½ miles by 4½ miles, exclusive of S. Lancashire lines. Population served, about 800,000.

Length of Tramways, single track, 163 miles. Number of Cars in use, 494.

FIG. 14.

on electrical reconstruction, exclusive of purchase-money from the tramway company, divided by 45 miles, equal to £23,300, of which £15,550 is accounted for by the permanent way, its electrical equipment, and the distributing cables. The contract price for the last section done, namely, 7 miles single between Kennington and Streatham, was just under £13,000 per mile. These costs from £13,000 to £16,000 may be compared with half the figures given in the third column of Table VII., facing p. 35, for overhead construction, namely, an average throughout the country between £7000 and £8000, and between £9000 and £10,000 for such places as Liverpool and Glasgow. The comparison is with one-half the total cost, because Table III., p. 31, shows that the items covered are 50 per cent. of the total cost. As for the total capital cost, the London County Council accounts do not as yet afford data from which to calculate it properly. Their central power station is only now in course of construction, and in the mean time they are buying their steam and using it in temporary premises in generating plant which is to be ultimately removed to the central station at Greenwich. Thus the complete capital outlay necessary for the lines already running has not yet been expended, while, on the other hand, much of what has already been expended will serve for a mileage much extended beyond what is now working. It is certain that the ultimate cost per mile of track will greatly exceed the above-mentioned figure of £23,300. An estimate of £26,800 has been made, but it will not surprise many engineers if this be eventually exceeded. From this estimate are excluded many preliminary and miscellaneous costs which are included in the figures given in Table VII., and also the whole cost of purchasing the original horse-trams from the private company which owned them. This purchase-money amounted to £897,000 for 40 miles of route, or £22,400 per mile. Halving this, it is equivalent to £11,200 per mile of single track; and this added to the cost of electrical construction already appearing in the accounts, makes the total £34,500 per mile of single track. The eventual total cost may be safely taken at £35,000. Thus the conduit system in London may be reckoned to involve over 75 per cent. more capital outlay than does overhead construction in Glasgow or Liverpool. The number of cars at present provided is 6·6 per single mile of track, which is a larger proportion than elsewhere in Britain. This difference in car density accounts for less than £1000. A large portion of the 75 per cent. excess is due to the heavy price paid for purchase of the old lines, and has nothing to do with the system of construction adopted. The excess cost of the conduit system is variously estimated at from £7000 to £10,000.

The London County Council accounts to date show the running costs on the conduit lines to be 7¾*d.* per car-mile. This is raised



Limits of area served, 8 miles by 5 miles.
Population served, about 500,000.

Length of Tramways, single track, 90 miles.
Number of Cars in use, 270.

FIG. 15.

Fig. 16.—Dublin United Tramways. Number of miles, single track, 47.

above normal by the heavy price paid for steam supplied from outside; but a critical examination of the accounts shows that there is little probability of its being reduced below 7*d*., exclusive of all depreciation. This may be compared with the average of 6¼*d*. in Table VII., and 5¼*d*. attained in Glasgow.

On the other hand, even during their first year, the London County Council electric lines have yielded a revenue of 11·94*d*. per car-mile, as contrasted with 10*d*. yielded by the horse-trams during the same period in the same district. The number of passengers carried per car-mile has been 11·95; so that the average fare paid per passenger is 1*d*. almost exactly. Nearly half the passengers pay the 1*d*. fare, and three-eighths of them pay a ½*d*. fare. The length of the ½*d*. stage averages about ¾ mile; while that of the 1*d*. stage varies from 1¾ to 2¾ miles with an average well above 2 miles.

28. Fig. 17 gives a map of the London County Council tramways at the end of 1904. On the map are marked the positions of the Greenwich Power Station and of six sub-stations at New Cross, Elephant and Castle, Kennington, Camberwell, Clapham, and Streatham. It includes those on the north side of the Thames, which are still leased to the North Metropolitan Co., but all of which will be electrified within a few years. It shows also the town ends of the United London Tramways, starting from Hammersmith and Shepherd's Bush, Kensington, which run to Kew, Hounslow, and Kingston, and to Ealing and Southall. It is proposed to extend these lines to Uxbridge, Maidenhead, and Staines, and this company will very soon have 76 miles of overhead line in operation.

29. The capital cost of the "surface contact," or "stud," system is intermediate between those of the overhead and conduit systems. The only example now at work in Britain is the Wolverhampton trams laid out on the Lorain design. Some detail information regarding this construction will be found later in Chapter VI. In France the Diatto stud trams have worked well in Tours, and the Diatto and the Dolter with fair success in Paris. The Schuckert design costs rather more, but affords greater safety from the danger of leaving live studs behind the cars. It has been successfully worked experimentally at Munich, but as yet has not been developed commercially. In Chapter VI. these, as also the Sylvanus-Thompson-Walker construction, will be described.

30. Each of these three main classes of tramway construction has its particular disadvantages and advantages. The overhead system is the least costly; and particularly for conversion of existing horse-trams to electric traction it offers special inducements, as it involves no necessary alteration or disturbance of the existing road-bed or rail-track, except that required for the bonding of the rails. This

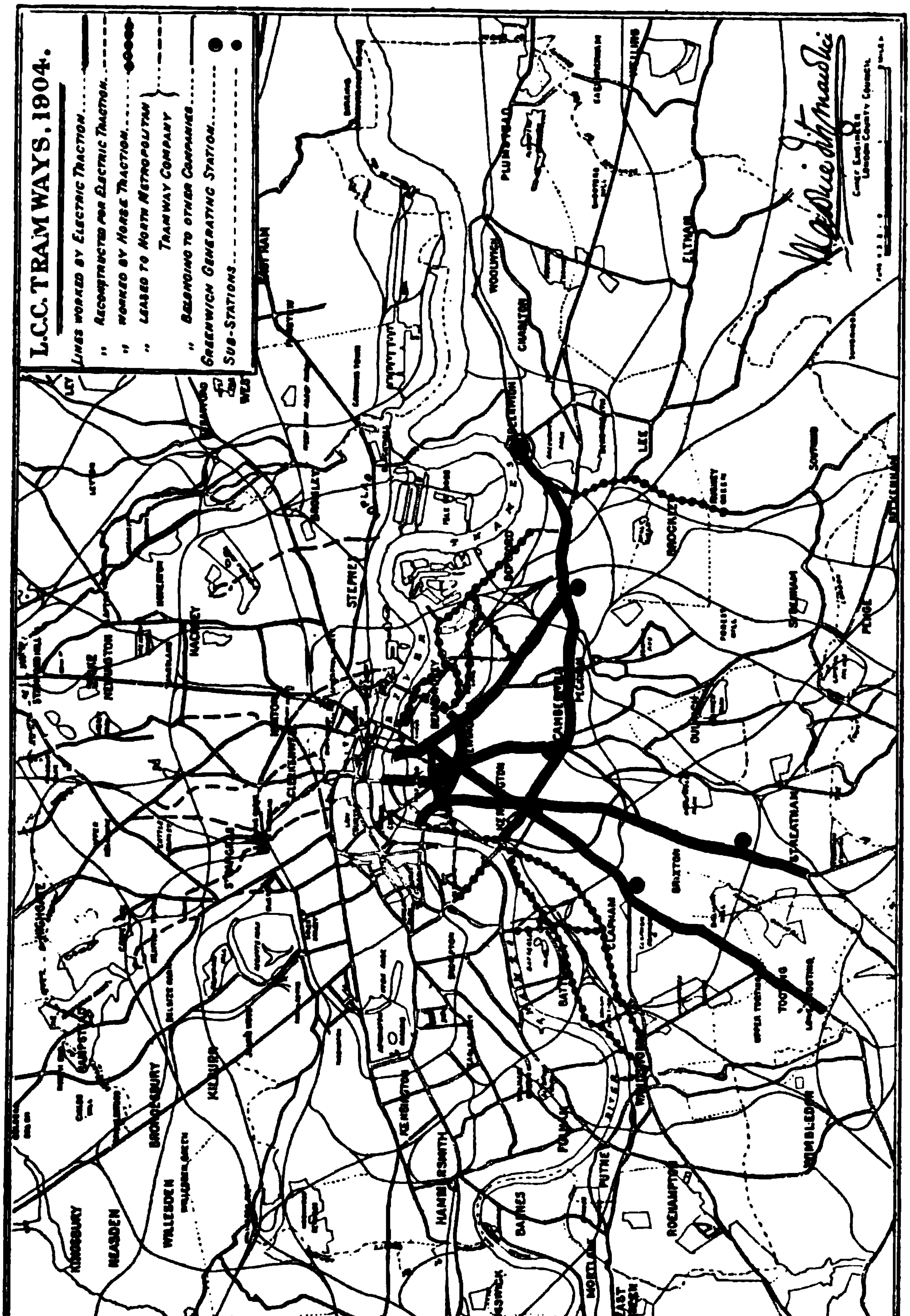

L.C.C. TRAMWAYS, 1904.
LINES WORKED BY ELECTRIC TRACTION
" RECONSTRUCTED FOR ELECTRIC TRACTION
" WORKED BY HORSE TRACTION
" LEASED TO NORTH METROPOLITAN TRAMWAY COMPANY
" BELONGING TO OTHER COMPANIES
GREENWICH GENERATING STATION
SUB-STATIONS

FIG. 17.

not only greatly lowers the cost of the new installation, but also avoids the serious disadvantage of much interference with the traffic during the installation. In regard to insulation of the working line-conductors, also, the overhead tram is greatly superior to either of its rivals. It is slightly more noisy than either of the others, but the difference is of relatively small amount as the greater part of the noise arises from the motion of the driving and trailing wheels on the track-rails, and this is equal on all systems. The only substantial objections to overhead lines are the unsightliness of, and danger from, the poles and suspenders and network of line wires at crossings, and the difficulty of arranging for insulated return currents. An insulated return would necessitate a second overhead wire and two trolleys, and this duplication would double the objections made on the score of ugliness and danger from breakage and fall of wires. In the earliest days of tramways, unfortunately, timber poles were used, which were almost or quite as ugly as telegraph poles, and even now the iron and steel poles do not compete in beauty with the most modern lamp-posts, although they are certainly much less ungraceful than the lamp-posts of twenty years ago. When the street is 50 feet, or more, wide, central two-arm posts, if of good artistic design, are really ornamental, and serve the useful purpose of dividing the opposing streams of traffic. Side poles with single corbel-arms cannot be treated so as to form a handsome feature in the landscape, and, when added to existing rows of dismally inartistic lamp-posts, produce a cumulative effect of hopeless melancholy in the view along the route. But if the old lamp-posts be rooted out and the new tram-posts be well designed, and made to serve the double purpose of tram and light service, the effect will be a marked improvement on the previous condition. The real difficulty is the danger from accidental fall of overhead wires. This is minimized by the use of guard-wires, but the addition of these makes the æsthetic objection to the network of wires intervening between the sky and the pavement of double force. This difficulty with overhead trams cannot be surmounted.

Both the other systems leave everything above the street surface absolutely unencumbered. Danger of accident from contact with live conductors is almost entirely eliminated. The conduit affords easy opportunity for insulated returns, and, in fact, most conduits are so made. This eliminates all objection on the score of electrolytic destruction of gas and water-pipes, and of disturbance of magnetic instruments and interference with telephones. Interference with telephone systems is, however, now a matter of no importance, as all such circuits are now provided with insulated return wires, so that outside disturbance has little or no effect upon them. The three objections to the conduit are its greater first cost, the leaving open

on the street surface a slot into which very narrow wheels, hoops, rods, etc., can penetrate. It also admits rain-water to the conduit, which seriously injures the insulation, and in times of flood practically destroys it altogether, so as to make it necessary sometimes to suspend the tram traffic altogether for short periods on special sections. The daily cleaning of the conduit is also a matter of considerable expense.

Except for the slight noise of the skate rubbing over the studs, the surface-contact system would be the ideal in respect of public convenience, if the danger of leaving studs alive could be surely and completely guarded against. Most forms of this kind of tramway have a movable mechanism embedded in the causeway under each stud, the studs being spaced 6 to 10 feet apart, and owing to the vibration and shock due to the traffic, these mechanisms get out of perfect mechanical condition, and thus occasionally stick and fail to break circuit. The Schuckert design removes all these switches to the side of the road, where they are exposed to no violent shock, and thus leaves nothing in the roadway that is not solidly fixed so as to need no inspection or repair. To do this involves extra lengths of copper connections, thus raising the cost. During heavy rains the insulation across the road surface between the studs and the rails is very imperfect; but as the studs are not charged except when they are covered by a passing car—that is, for only a second of time--and when, also, they are thus protected from the falling rain, the leakage current is unimportant. It is not serious enough to prevent the running of cars even when the track is covered with melting snow.

Nevertheless the surface-contact trams have not so far achieved any striking commercial success.

31. One part of the probable future work of tramways is the carrying of parcels. The development of this business is only now beginning to be attempted, and only in a very few places. A parcels organization is proposed throughout the South Lancashire network of trams. Evidently it must be arranged so as not to impede the passenger traffic. Collecting and distributing offices at frequent intervals along the route appear to be necessary to accomplish this, although the collection of odd light parcels at intermediate points should offer no difficulty. Especially in outlying suburban and rural districts, this parcel delivery is likely to grow into a very important part of tramway business.

CHAPTER III

ECONOMIC DEDUCTIONS FROM STATISTICS AND TECHNICAL CONDITIONS

1. TABLE VII. in the last chapter shows a good deal of the reasons why tramways are more profitable in one place than in another. The places are there arranged nearly in the order of the profitableness of the enterprise as an investment of capital, and as measured by the figure in the column 19 entitled "Ratio of annual excess of revenue over working costs to capital outlay." This is by no means a complete measure of the all-round utility of the undertaking, but it is the best that can be deduced from the published accounts.

2. The length of line in each place is quoted in the table, as, up to certain limits, the larger the undertaking is the more economically is it possible to manage it. If K be the necessary capital outlay and L the number of miles of single track, the relation between K and L under given general conditions is roughly K = constant + kL, where k is a constant factor, and the "constant" an initial, or "preliminary," outlay not affected by the magnitude of the whole. It is due

partly to parliamentary and legal expenses and costs of "promotion," but also largely due to the central generating station, the cost of which again depends upon the car-mileage work to be done each day. This station involves large outlay, whatever be its size or the total power generated in it. In order to make the initial constant as low as may be, large central stations to serve districts where gradual development of traffic is anticipated, are now always built so as to leave freedom for extensions from time to time. The factor k is obtained from the cost, actual or estimated, of these extensions, not from the cost of the first installation. It varies not far above and below £6000 per mile.

But the losses in distant transmission of energy put a limit to the distance to which it can be economically supplied from a single central station. With present methods this limit does not exceed ten miles from centre to the extremities of the system, transforming sub-stations and high-pressure transmission to them being employed for much less distances. Now it is easy to get a stretch of ten miles and more for a tramway system that is of small business magnitude, and likely to be on that account uneconomically worked. Therefore simple length of line is no criterion from which to judge of conditions favourable or otherwise to tramway success.

3. If it were possible to insert in Table VII. the ratio of the length of track to the area covered, this would be a good indication of favourable condition. The larger this ratio, the shorter is the average distance to which the energy has to be transmitted. In respect of low mechanical working cost, this is the main consideration: a close network of lines, provided they are busy, is that which can be served cheaply. From this point of view the ratio given in the first column, namely, that of track length to route length, which would be two if the whole were double track, is a good indication of the character of the undertaking.

The reciprocal of this ratio, namely, that of the area served to the length of line, is a sort of "mean hydraulic depth," or mean distance the passengers have to walk to and from the cars; and the less this mean distance, the more freely will the cars be used by the residents.

For two fundamentally influential reasons, therefore, is this "density of track per square mile," or $\dfrac{\mathrm{L}}{\text{area served}}$, one of the main features favourable to tramway prosperity.

4. But in order that this density may be useful, the area must be populous in due proportion. The total resident and business population per mile of track is therefore also an essential influence. Unfortunately, the census gives only the resident population, whereas the day population of the shops and factories is as important a factor as the other. If the two were added together, of course the same

persons would be counted twice over; but this is what would be desirable in measuring the fruitfulness of the area in tramway revenue.

Columns 3 and 4 show that it is poor policy to build cheaply or to starve the line in respect of numbers of cars. On the other hand, it also shows that extravagant capital outlay, even under otherwise very favourable conditions, eats up the legitimate profits. The number of cars per mile of track is a sure indication of the fertility of the area and of the vigour with which it is cultivated.

The results are shown in the following columns, and in none better than in "Annual passengers per mile of single track." Apart from all money considerations, and looking on the tramways solely as a convenience and help to the public, this is a *complete* measure of success. It is the simple and direct indication of how much the lines

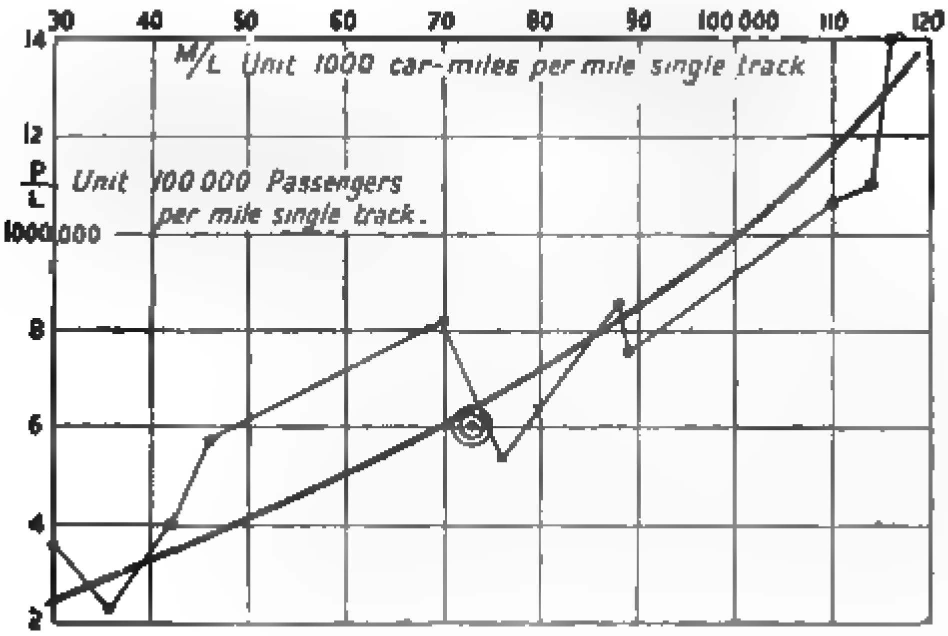


Fig. 18.

are used. It is instructive to compare this column with that giving the "passengers per car-mile." The figures do not run at all parallel. To cram the cars full, that is, to overload them at maximum traffic hours, as in Nottingham, Halifax, and Aberdeen, without a high number per mile of road, is bad policy; it is felt as a hardship by the public, and it, in fact, produces no brilliant results in the money accounts, in spite of its producing a high revenue per car-mile.

5. High results per car-mile are unsafe evidence of success. They can easily be obtained by starving the lines of due service. By so doing the standing capital charges, as also the "stand-by" working costs, are greatly raised per unit of useful service performed. What is technically meant by stand-by working costs are those which run on whether or no useful work is being performed.

The above may be otherwise expressed by saying that starving the lines of service during slack hours ensures a bad load-curve. The load-curve and the "load-factor" are mainly influential in determining success or the reverse. The load-curve is, to a very large extent, uncontrollable by the management; but its bad character may be very greatly aggravated, or may be substantially ameliorated by skilful nursing of its low-lying parts.

It is instructive from this point of view to note the close general correspondence between columns 4, 6, and 5, namely, numbers of cars, annual car-mileage, and annual numbers of passengers, per mile of track. In diagram Fig. 18 is plotted a series of points for a number

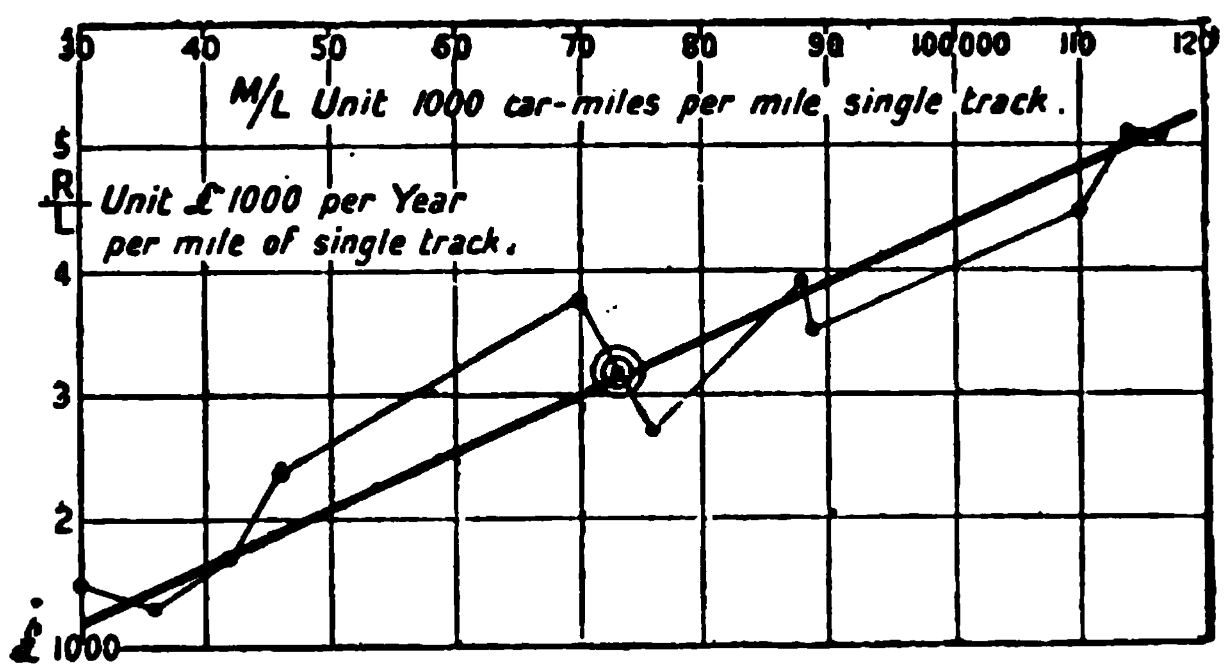


FIG. 19.

of typical installations, whose horizontal co-ordinates give the annual car-miles per mile, and whose heights give the annual passengers per mile. The thick continuous line gives a fair mean of these. It is a curve with slight upward curvature.

In diagram Fig. 19 are given, for the same places, the relations between car-miles per mile and traffic revenue per mile. In this case the mean relation is best represented by a straight line, which is drawn across the diagram. Its equation is—

$$\frac{R}{L} = 0{\cdot}045\frac{M}{L} - £150$$

6. The following algebraic expression of the profitableness of a tramway is introduced, not as a means of making an accurate estimate, because it contains several factors whose precise value it would be difficult to ascertain from statistical results; but as a concise manner of showing how the economic problem is approximately affected by each of a considerable number of conditions:—

Let L = length in miles of single Track;
C = number of Cars;
K = Capital outlay;
R = annual Revenue;
W = „ Working costs;
P = number of Passengers carried per year;
M = „ Car-Miles run per year;
i = annual rate on capital covering Interest and Depreciation.

Then for a given average proportion of the C cars being out of work for repairs, cleaning, slack demand, and so forth, and for a given average speed of travel, and given time-interval between cars, C is proportional to M, or—

$$C = cM$$

Also for a given average fare paid per passenger, R is proportional to P, or—

$$R = rP$$

For a given density per square mile, and given character of the population, P is partly proportional to the length L and partly to the frequency of the time-service, which latter is, as before explained, proportional to $\frac{M}{L}$. It may thus be written—

$$\frac{P}{L} = p_m\frac{M}{L} - p_l$$

As already noted, the mean found from Fig. 19 gives $rp_m = £0{\cdot}045$ and $rp_l = £150$.

The capital outlay is partly due to the length of track, and partly to the number of cars owned. In regard to the cars, besides the purchase price of the cars themselves, there is also the car "stabling" accommodation to take into account. The capital outlay on the generating station, on the distributing cables, etc., depends on the maximum rate of working, on the shape of the load-curve, on the storage devices adopted to flatten or steady the load-curve, on the compactness of the tramway network. But, under similar conditions of this sort, the horse-power required, and the variable part of the capital sunk in the central station and distribution, may be taken as proportional to the yearly car-mileage, and this has already been taken in constant proportion to the number of cars C. The total capital expenditure may, therefore, be written—

$$K = K_0 + k_lL + k_cC$$
$$\text{or} = K_0 + k_lL + k_mM$$

where K_0 is the initial amount unaffected by the magnitude of the system.

As an illustration of what may be the proper values of the factors in this formula, there may be taken—

$$£K = £50,000 + 6000L + 0{\cdot}08M$$

The working costs depend upon the length of track in respect of repairs and maintenance of roadway and line electrical equipment and in respect of energy-distribution losses. They depend on the number of cars in respect of cleaning, stabling, and repairs. They also depend upon the annual car-mileage in respect of energy usefully consumed and lubrication and repairs of the motors, and also in respect of wages of conductors, drivers, and most general expenses. As the number of cars and the annual car-mileage are interchangeable terms, the annual working costs reduce to an expression quite analogous to that for capital outlay, namely—

$$W = W_0 + w_l L + w_c C$$
$$\text{or} = W_0 + w_l L + w_m M$$

Not much error is introduced by simplifying this formula by omitting the constant W_0, or putting it zero. An illustration of values of the coefficients in the formula thus simplified is—

$$£W = 150L + 0{\cdot}02M \text{ per year with L in miles.}$$

All these factors, c, r, p_l, p_m, k_l, k_c, k_m, w_l, w_c, and w_m, are here taken as "constants," but their values will vary considerably according to local circumstances. It is much better to call such ratios "factors" than "constants."

After providing for interest and depreciation on capital, the net annual profit (over and above interest) is—

$$R - W - iK$$

This may be reduced to per £ of capital by dividing by K; or to per mile of single track by dividing by L; or to per car owned by dividing by C; or to per car mile run by dividing by M.

The ratio to K, the capital expenditure, is that in which most interest is commonly felt. It is—

$$\left.\begin{array}{l}\text{Ratio of Net Profit over and}\\ \text{above interest and deprecia-}\\ \text{tion to capital expenditure}\end{array}\right\} = \frac{R - W}{K} - i$$

$$= \frac{r\left(p_l + p_m\dfrac{M}{L}\right) - \left(w_l + w_m\dfrac{M}{L}\right) - \dfrac{W_0}{L}}{k_l + k_m\dfrac{M}{L} + \dfrac{K_0}{L}} - i$$

Here C may be substituted in place of M, if also w_c and k_c be substituted for w_m and k_m.

It is seen how the effect of the two initial constants W_0 and K_0 depends on the magnitude L. The greater L is the smaller is the deduction $\frac{W_0}{L}$ in the numerator, which increases the net profit; and at the same time the smaller also is the addition $\frac{K_0}{L}$ to the divisor, which also increases the profit.

To illustrate this formula, insert the values already given above, when it reduces to—

$$\frac{R - W}{K} = \frac{0{\cdot}025\frac{M}{L} - 300}{0{\cdot}08\frac{M}{L} + 6000 + \frac{50{,}000}{L}}$$

The results of this formula with these coefficients are given in Table VIII. for 25, 50, 75, and 100 thousand car-miles per mile and for L 50 and 100 miles.

TABLE VIII.—RATIO OF NET REVENUE TO CAPITAL EXPENDITURE.

$\frac{M}{L}$ car-miles per mile, single track.	Any length L.	L = 50 miles, single track.	L = 100 miles, single track.
Unit 1000.		Per cent.	Per cent.
25	$\dfrac{0{\cdot}325}{8 + \frac{50}{L}}$	3·6	3·8
50	$\dfrac{0{\cdot}95}{10 + \frac{50}{L}}$	8·6	9·0
75	$\dfrac{1{\cdot}575}{12 + \frac{50}{L}}$	12·1	12·6
100	$\dfrac{2{\cdot}2}{14 + \frac{50}{L}}$	14·7	15·2

N.B.—These results are rather worse than actually attained results at the lower part of the scale and rather better than those at the higher part. The coefficients make the result vary rather too rapidly with $\frac{M}{L}$.

7. It is also seen how the result is affected by the traffic density or annual car-mileage per mile of track, $\frac{M}{L}$. The factor of $\frac{M}{L}$ in the numerator is $(rp_m - w_m)$, and that in the divisor k_m. In order that increase of $\frac{M}{L}$ may be profitable, not only must the former be positive —that is, $rp_m > w_m$—but there must also be fulfilled the condition—

$$\frac{rp_m - w_m}{k_m} > \frac{R - W}{K}$$

We have seen that the average fare per passenger r is about 1*d.*; and from Table V. we find w_m to be about 5*d.*, and w_l to be from £150 to £250. From Table III. it may be deduced that a mean value of k_m is somewhere near 18 pence. These values would give the arithmetically simpler form—

$$p_m > 5 + 18\frac{R - W}{K}$$

as the condition of its being paying business to increase $\frac{M}{L}$, the car-mileage per mile of track. In Table VIII. above the value assumed for rp_m is £0·045 = 10·8*d.*, and that for k_m is £0·08 = 19·2*d.*

Table VII. shows that $\frac{R - W}{K}$ ranges in different places from 0·04 to 0·13. For the following series of this ratio, the least value of p_m fulfilling this condition is calculated below.

	$\frac{R - W}{K}$ =	0·04	0·06	0·08	0·10	0·12	0·15
Pence	p_m >	5·7	6·1	6·5	6·8	7·2	7·7

Table VII. does not furnish data from which to estimate p_m with any close approximation. The differences of local condition are too great to permit of the elimination of the separate influence of the car-mileage upon the passenger traffic; while also the advance of each particular place from year to year has as yet been too erratic during the very short period yet elapsed since electric traction was introduced, and has been too much affected by experiments on the part of the management to allow of deduction of any sure law. Apparently p_m lies between 6 and 15. The whole factor $\left(p_l + p_m\frac{M}{L}\right) = \frac{P}{L}$ is given in Table VII., its average being 600,000. Its range

is from 230,000 at Coventry, where $\frac{M}{L}$ is 36,000 and $\frac{R-W}{K}$ is 0·043, to 1,400,000 at Glasgow, where $\frac{M}{L}$ is 116,000 and $\frac{R-W}{K}$ is 0·132. Calculating from this extreme range, one finds $p_m = 14·6$. But making the comparison between other figures recorded in Table VII., very different values are obtained. All such comparisons, however, make p_l negative; and common sense must lead to the conclusion that there is in each case a minimum number of car-miles more than which must be run before the public find the service convenient enough to be useful at all. The plotted results of Table VII. in diagram (Fig. 19) give $rp_m = 10·8$ for average conditions and $rp_m = 13$ for most favourable conditions. With the former coefficient, the passenger traffic would approach zero when the mileage run per mile of track is reduced to between 3000 and 4000. The curve runs down to zero value of $\frac{P}{L}$ at $\frac{M}{L} = 30,000$; and 30,000 is a much safer minimum service to assume above which to expect a beginning of passenger traffic. The curve of Fig. 18 turns upwards, making p_m equal to 8·8 at $\frac{M}{L} = 50,000$, and equal to 16 at $\frac{M}{L} = 100,000$.

For the values $r = 1d.$; $p_l = -96,000$; $p_m = 10$; $w_l = £200$; $w_m = 5d.$; the ratio of net revenue to capital becomes

$$\frac{R-W}{K} = \frac{\frac{1}{48}\frac{M}{L} - £200 - \frac{W_0}{L}}{k_l + k_m\frac{M}{L} + \frac{K_0}{L}}$$

and here k_l may be from £6000 to £9000, and k_m from $\frac{15}{240} = £\frac{1}{16}$ to $\frac{20}{240} = £\frac{1}{12}$. In this simplified form the commercial influence of the factors M and L, and of their ratio to each other, becomes very clear.

8. It is sometimes desired to estimate the effect of differences of capital outlay upon the total cost per car-mile. This is a very simple arithmetical proportion when the car-miles run per year per mile of track are assumed. Thus if 100,000 car-miles per mile of single track be assumed, and 10 per cent. per year be taken as the total capital charges, then every increase of £1000 per mile in the capital outlay means $\frac{1000 \times 240 \times 0·10}{100,000} = 0·24$ of a penny per car-mile. If 6 per cent. instead of 10 per cent. be the rate of annual capital charges, and 80,000 car-miles instead of 100,000 be assumed, then each £1000 per mile means $0·024 \times 6 \times \frac{100}{80} = 0·18d.$ per

car-mile. Dr. A. B. W. Kennedy estimated for the London County Council that 5 per cent. capital charges on each £1000 with 100,000 car-miles per mile meant $\frac{1}{8}d.$ per car-mile, the exact figure being $0{\cdot}024 \times 5 = 0{\cdot}12$.

9. It is an equally elementary arithmetical operation to find the varying capital charge per hour for varying load-factor. Ten per cent. per year on £1000 is 24,000*d.* per 365×24 hours, or $\frac{1000}{365} = 2{\cdot}74d.$ per hour. If the plant of £1000 capital cost worked continuously, the 10 per cent. charge would mean $2{\cdot}74d.$ per working hour; but if the load-factor be λ—that is, if the total work done per year be the fraction λ of 365×24 hours' full work—then the 10 per cent. capital charge per working hour, or per each full hour's work, whether done in one hour or any longer or shorter time on fractional or overload, is $\frac{2{\cdot}74}{\lambda}d.$ Thus if the load-factor be 0·3 it would be $\frac{2.74}{0{\cdot}3} = 9{\cdot}1d.$; and with a load-factor of 0·4 it would be 6·85*d.*

10. Tramways in this country are designed and built in accordance with the provisions of the Tramways Act of 1870, the Light Railways Act of 1896, and the Board of Trade Rules and Regulations under these Acts. The B.T. Regulations are revised from time to time. The last revision was made in April, 1903.

The main constructive restrictions imposed by these regulations are as follows :—

(1) The least distance between the curb of the footpath and the nearest rail shall be 9 feet 6 inches, and 10 feet 6 inches if railway carriages or trucks are to pass over the line. This rule may be deviated from for any isolated length of less than 30 feet, and for longer lengths by special consent.

(2) The distance between double lines must be such as to leave at least 15 inches clear between the widest cars or trucks when passing each other.

Thus the width of roadway between curbs must be at least 19 or 21 feet, plus the rail-gauge over the outsides of the metals, for single tracks; and 20 feet 3 inches or 22 feet 3 inches, plus the rail-gauge plus the outside width of one car, for double track. Common widths of car are 6 feet, 7 feet, and 7 feet 6 inches. The commonest rail-gauge is 4 feet 8½ inches.

(3) No provision is made in the rules for the use of other than continuous current; but the B.T. promises to consider rules for alternating current when it may be proposed to use it.

(4) No uninsulated return conductor may be laid further than 3 feet away from the running rails, and any such conductor must be bonded to the rails at spacings not greater than 100 feet.

(5) Either the negative terminal of the generator, or the nearest uninsulated part of the return to this terminal, must be connected to two separate earth-plates at least 20 feet apart. The electrical resistance between these earth-plates through the earth must not be greater than such as will give at least two ampères with 4 volts potential difference. The resistance so specified may be less than 2 ohms if there be electrolytic counter-electromotive force arising in the earth between the plates. A water-main of 3 inches or more diameter may be used in place of the two earth-plates, and the earth-plates must not be within 6 feet of any other pipes than such a water-main connected to them.

(6) Seven volts is the maximum fall of potential between any two points of an uninsulated return, and the return current through the earth-plates to the generator may not exceed 2 ampères per mile of single track or 5 per cent. of the total current.

(7) The P.D. through the earth between any part of the uninsulated return and any neighbouring pipe, plus any electrolytic counter E.M.F. that may arise in the earth, must be less than the voltage of three Leclanché cells in series, *i.e.* rather under $4\frac{1}{2}$ volts, from the return to the pipe, and less than that of one such cell, or $1\frac{1}{2}$ volts, from the pipe to the return.

(8) Every insulated conducting line, out or return, except feeders, must be made in sections not longer than $\frac{1}{2}$ mile, and these sections must each be capable of isolation for testing.

(9) The insulation of insulated conductors must be such as to prevent leakage of more than 0·01 ampère per mile of tramway; and if this leakage at any time rise above 0·5 ampère, it must be stopped within 24 hours. This insulation must also be maintained at or above 10 megohms in one mile.

This rule does not apply when line and return are laid inside a conduit. In this case, if the leak exceed 1 ampère per mile, it must be stopped within 24 hours.

The reference numbers here do not correspond to the numbers attached to the B.T. Regulations.

The object of these rules from that referred to in (4) onwards is evidently to protect the general mass of the earth from excessive stray, or "vagabond," currents. These are supposed to produce electrolytic injury to metal pipes laid in the earth. The corrosion of the metal occurs where the current leaves the pipe, and not at all where it enters. Hence the difference between the $1\frac{1}{2}$ and the $4\frac{1}{2}$ volt tests provided for in (7). This, which is the B.T. Regulation number (6), is apparently intended to ensure "separation of the uninsulated return from the general mass of the earth, and from any pipe in the vicinity," as this is stated to be one of the objects in view; and this presumably means to ensure such resistance between these as will prevent

the passage of excessive current. But the method of the test is to reduce potential difference, and this can be done by well bonding the pipe and the rail together. Such bonding, with the consent of the pipe-owners, is allowed by the B.T., although not referred to in their rules. The bond, if placed where the rail tends to be at lower potential than the pipe, and where, therefore, it will lead any current out of the pipe, must prevent corrosion in its neighbourhood, because the current, in order to corrode, must pass from the metal into damp electrolytic earth. If, however, the bond be made at points where the rail is above the pipe potential, then it can only be disadvantageous.

The evident general aim of the rules is to ensure, as far as may be, that nearly the whole of the vagabond earth current should find its way back to the generating station through the earth-plates attached to the negative terminals of the generating plant.

It is to be noted that these regulations nowhere limit the voltage to be used in any insulated conductors. If the insulation be sufficient to prevent the forbidden leakage, then the tension may be high or low. Nevertheless, sanction has not yet been given to any voltage above 600, and 550 is what is commonly employed.

11. Iron rails have an electrical resistance 6½ times greater than copper bars of same section. Their resistance per mile is, therefore, 0·28 ohm divided by the sectional area in inches. A rail weighing 100 lbs. per yard has a section of exactly 10 square inches, and would have, therefore, a resistance of 0·028 ohm per mile if it were continuous. The copper bonding introduces from 10 to 20 per cent. extra resistance with 30-feet rail-lengths, and half that with 60-feet rails. A bonded rail, therefore, has a resistance per mile equal to between 3·0 and 3·5 ohms divided by the weight per yard, the variation depending mainly on the style of bonding. Two rails well cross-connected have half this, and four rails one quarter of this resistance.

The average car takes 15 ampères to drive it under normal conditions, but at starting and on heavy gradients its consumption is often doubled and occasionally trebled. It is assumed that some six cars contiguous to each other on the road may sometimes use their double consumption at the same time. More than six or eight contiguous cars will hardly ever all together use maximum current. In crowded districts, when a block occurs, the rule that no driver should start his car into motion at the same time as the car in front of him is also doing so should be strictly enforced. It may be assumed that a group of twenty cars will never use more than 50 per cent. over their total average current; but less than 50 per cent. is seldom assumed in estimates for any group of cars, however numerous. In Fig. 9, from Leeds on a normal day, the central station diagram does not show more than 20 per cent. variation up or down from the mean, and in Fig. 10, from

the same place on August Bank Holiday, the greatest variation is 25 per cent. But on individual 3- or 4-mile sections of the whole system, the variation must be much greater than at the central station.

To illustrate the calculation of the fall of potential along the rails, assume a double track of four rails, each 100 lbs. per yard, loaded with ten cars all at one time, taking 30 ampères each. or 300 together, and spaced in pairs equally along the mile. Assume the rail resistance (four rails cross-bonded together) as 0·009 ohm per mile. The drop of voltage in this mile of rail, seeing that $2 \times 30 = 60$ ampères is discharged into the rails at points $\frac{1}{5}$ mile apart, will be—

$$\begin{aligned} &0·009 \times \tfrac{1}{5}(60 + 120 + 180 + 240 + 300) \\ &\quad = 0·009 \times \tfrac{60}{5}(1 + 2 + 3 + 4 + 5) = 0·009 \times 12 \times 15 \\ &\quad = 1·62 \text{ volts in 1 mile} \end{aligned}$$

The similar calculation for twenty cars spaced in pairs equally along 2 miles of double track, and each car taking $22\frac{1}{2}$ ampères, or the pair 45 ampères, gives—

$$\begin{aligned} &0·009 \times \tfrac{45}{5}(1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9 + 10) \\ &\quad = 0·009 \times 9 \times 55 = 4·455 \text{ volts in 2 miles} \end{aligned}$$

With 45 ampères per pair of cars, any number of miles l would give the voltage drop in the l miles equal to—

$$\begin{aligned} 0·009 \times \tfrac{45}{5} \times \frac{(1 + 5l)5l}{2} &= 0·009 \times 45 \times \frac{(1 + 5l)l}{2} \\ &= \text{nearly } (0·2 + l)l \text{ volts} \end{aligned}$$

This equals 7 volts, the B.T. limit, at just over $2\frac{1}{2}$ miles.

This corresponds to an extreme limit of traffic density, involving the discharge into the rails of 225 ampères per mile of route. Such density occurs but rarely, or never, over so long a length as $2\frac{1}{2}$ miles, even in crowded cities like Glasgow and Liverpool.

If w be the weight in lbs. per yard of one rail, and $\frac{0·9}{w}$ the resistance per mile of four cross-bonded rails, and if there be C cars per mile evenly spaced, each discharging $22\frac{1}{2}$ ampères into the rails, then the drop in l miles in the rails is nearly—

$$\frac{10}{w}(1 + Cl)l \text{ volts}$$

the exact factor corresponding to the data being $10\frac{1}{8}$.

This last gives 7 volts in a length—

$$l = \frac{1}{2C}(\sqrt{2{\cdot}8wC + 1} - 1) \text{ miles}$$

a sufficient approximation to which is—

$$l = \sqrt{0{\cdot}7\frac{w}{C}}$$

With $w = 100$, this gives—

for $C =$	10	8	6	4	2
$l =$	2·6	2·9	3·4	4·2	5·9

and with $w = 80$—

$l =$	2·4	2·6	3·0	3·7	5·3

These calculations are based (1) upon an assumed symmetrical distribution of the cars not corresponding to the actual distribution; (2) upon an assumed maximum average current from the cars, while no exact average of the maxima exists; and (3) upon a neglect of the conductive assistance given by the earth, which cannot be calculated, and whose amount varies very erratically. No close calculation of these limiting distances is, therefore, justifiable. It appears that up to at least one-fifth of the whole current may pass through the earth. The resistance through 1 to 2 miles length of the earth appears to range from four to ten times that through an equal length of four-rail route.[1]

12. The risk of electrolytic decay of pipes laid in the earth arises from current from the pipe to the rail, and this occurs only when the pipe is at higher potential than the rails. Now, if the resistance of the rails per yard be uniform, then throughout any length traversed by a given amount of current the fall of potential per yard is uniform. Also if there be connected to the rails at the beginning and end of this length another conductor of uniform resistance per yard, then, whether this resistance per yard be large or small, and whatever may be the proportion of the current shunted through it, the fall of potential along this shunt conductor per yard will also be uniform. Under these conditions there must be equal potentials at the same proportionate distances along the rails and the shunt, and there cannot be any cross-current between such similar points on the two. Such cross-currents only arise from want of uniformity in the resistance

[1] The *specific* resistance of clay and sand is some 15 million times that of rail-iron, and that of concrete about 80 million times the same. The section of clay or sand giving ten times the resistance of four 100-lb. rails, would be over 200 yards squared.

per yard along the length of either rails or shunt. Such want of uniformity as exists in the rails at their bonded joints, etc., is unimportant. In the shunt the resistance per yard length is least, and the potential drop least rapid where the section is greatest. Where the current enters the earth from the rails, it follows through the earth a path of restricted sectional area, and in the middle of its traverse through the earth, it follows a path of very large section. The restriction at parts of the path is called the "gathering" of the current. It is evident that the fall of potential through the earth will be more rapid near the two ends where the current leaves and re-enters the rails.

In Fig. 20, if current be supposed to leave the rail at A and to re-enter it at B, and if the thin straight line represent the uniform drop of potential along the rail, the thin curve, or some curve of similar character, may represent that through the earth. The difference of height between curve and straight line, shaded in Fig. 20, represents the voltage available to drive cross-currents between the two. For symmetrical gathering in the earth at the two ends of the earth path, the cross-voltage is zero at mid-length; it is from rail to earth throughout the first half, and from earth to rail throughout the latter half.

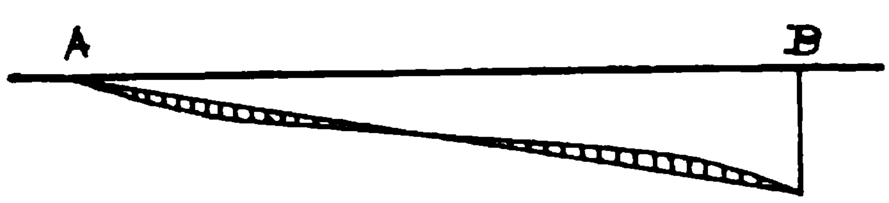


Fig. 20.

The general character, shown in Fig. 20, of the symmetrical problem is not in any way interfered with by the fact that current enters the rails from each car, and that the amount of return current, as also the potential drop per yard along the rails, are, therefore, very different at different parts of the tram-route. The return current from each car may be quite correctly considered apart from the others. But no such symmetry as above supposed in the earth passage actually exists. Hard rock, water-laden gravel, etc., and metal pipes, produce large and abrupt changes of conductivity; and instead of the smooth and simple curve of Fig. 20, the actual curve must be very irregular and ragged. It is worth noting, however, that it must always have a downward slope at every part of its length. Along the length of iron pipes, and especially of water-pipes, this downward slope is probably nearly always so small as to approach zero. In the worst case the interposition into the earth path of a considerable length of metal pipe nearly parallel to the rails is to slightly lessen the voltage from earth to rail at the end of the pipe most remote from the central station, and to slightly raise it at the nearer end.

In the opinion of most engineers the danger of appreciable electrolytic decay of pipes from tramway currents is non-existent. The

important point to keep in view is that the quantity of evil result is in ratio to the quantity of current, and has no direct relation to voltages or potentials. It is, therefore, unfair to press the B.T. Regulations hardly as against tramways serving a sparsely populated district with only a few cars along the line, while in crowded city tram networks the quantity of vagabond earth current may be enormous with uninsulated returns. It may develop to such magnitude that the observance of the present B.T. Regulations can have no appreciable effect upon the vagabond effects. For instance, there might be several thousands of ampères passing through the earth from one iron pipe to another such pipe without any infringement of the rule as to the $1\frac{1}{2}$ volts between either pipe and the nearest rail.

13. The inductive electro-magnetic disturbances producible by the probable enormous future development of electric current transmission of energy for tramways and other power purposes, appear to offer much more serious difficulties than do the risks of electrolysis. All electro-magnetic instruments and similar apparatus are disturbed as much by the outgoing as by the return currents. The currents for power purposes may disturb each other. Fortunately, large powers are now seldom transmitted except at high voltage with correspondingly small current, and all such transmission is arranged with insulated non-inductive out and return conductors. Whatever be the voltage, and whatever the current, the cure for these disturbing effects is to lead the return current back alongside of, or parallel to, and at no great distance from, the outgoing current. This can only be done by means of insulated returns in all circuits carrying considerable amounts of power. The cost of durable rail-bonding, so as to fulfil the B.T. Regulations for uninsulated returns, adds very heavily to the cost of the track, and makes the uninsulated rail-return in no very great ratio less costly than an insulated return would be. Thus, in conduit tramways there has been for long past no doubt about the advisability of using an insulated return. The real difficulty in using it on overhead tramways is the strong objection to doubling the number of overhead wires, even the one wire being considered a disfigurement and a danger in streets.

The author has long been of opinion that the real cure is to raise the voltage from the present 550 to, say, 1500 or 2000, with a corresponding reduction of current and of size of line-wire. The losses of energy in transmission, which are heavy, would be lessened; the length of sections fed by separate feeders might be increased; the danger from breakage of wires from wind and snow would be reduced; and the safety to the public would be almost certainly increased because considerable increase of voltage always carries with it a quite disproportionate increase of expenditure of thought and money in the

provision of more or less absolute security against accident throughout the whole design in detail and *en block*.

This conclusion is greatly strengthened by consideration of the cost, not only of the rail-bonding, but also of the "return-feeders" and "sucking boosters," which have been found necessary on most modern heavy traffic net-works. The central station being often at some distance from the main tram-line, either a tram-siding must be run up to the station, or else the rails of the main route connected by insulated cables to the station. As the rails at the point of connection will be at earth potential, the earth-plates, by B.T. rule, being connected to this junction, the negative bus-bars of the station are then below earth potential by a voltage equal to the return current multiplied by the resistance of this cable. The rails will not carry, under the 7-volt limitation, more than the current from 2½ miles of fully loaded heavy traffic. It follows that such insulated return cables have to be led from the station to various points in the route-plan. These cables are called "return-feeders," or "rail-feeders."

14. It would be useless to divide this plan into isolated sections as each has to be earthed; and, moreover, the neighbouring return-feeders will help each other when any one of them is overloaded, if the rails be well bonded throughout. Taking, however, the whole as divided ideally into sections, each drained by one return-feeder, the length of each such section may be about double the above 2½ miles, or such other length as the amount of traffic and the size of rail demands. Half of each such section may be looked on as draining into the nearest feeder; but actually the current from each car will split, part going to one and part to the other feeder in inverse proportion to the resistances of the two paths to the central station.

All these feeders return to the one negative bus-bar, and are there continuously kept all at the same potential. At their junctions to the rails they are all continuously kept as near as may be to earth potential by connection to their earth-plates. Thus the fall of potential along each feeder must be, or, on the steady average, ought to be, the same. It equals the product of length of feeder by current carried divided by sectional area. If, therefore, each is to carry an equal mean current, the copper section of each ought to be proportional to its length; or if, for the sake of using the same size of cable throughout, all the sectional areas be equal, then each ought to serve a length of tram-route which will throw along it a current inversely proportional to the length of feeder to station. Outlying suburbs will, of course, throw in less current per mile than central positions where several routes converge, and where the passenger loads per car are heavier.

It is, however, not at all exact to suppose that each rail-feeder junction is kept always to uniform earth potential. If this were so,

the voltage from each car to the feeder-junction on either side of it would be the same, and the current would split in the inverse proportion of the two distances of the car to the junctions. These unequal currents along the two feeders would cause unequal drops of voltage from the rail-junctions to the central station bus-bar, a result incompatible with equal potentials at the two junctions. Actually the current will split more nearly in inverse proportion to the two composite resistances along rail and feeder, and the currents so proportioned will establish potentials at the two junctions which are not equal and cannot both equal mean earth potential. The result is an earth current from at least one of the junctions through the earth-plate connected to that junction, and this earth current may sometimes be large. This deviation of part of the current through the earth again disturbs the assumed proportion in which the whole current from the car splits on entering the rails from the car-wheels. The disturbance of this proportion corresponds with the substitution, for each feeder resistance, of the less resistance of feeder and earth combined.

Instead of proportioning the section of each return-feeder in the way described above, a proportionment which cannot be correct at all times, small "boosters" may be inserted between the station ends of the feeders and the bus-bar. "Boosters" are dynamos inserted in special branches of an electric complex in order to create extra local E.M.F., and so modify the distribution of current and potential. On a return-feeder a booster drives, or, as it is usually termed in this connection, "sucks," extra current through the feeder on which it is placed, thereby relieving other feeders of some of the current they would carry if this booster were not acting. The booster is generally electro-motor driven. If it be series wound, it produces an extra fall of potential along the feeder proportional to the momentary amount of current to be sucked, and the energy of its action is thus automatically regulated in accordance to the ever-varying need of it.

15. In a large and complex system dealing with heavy currents, all these methods—earth-plates, insulated rail-feeders, boosters—of conforming to the B.T. Regulations for uninsulated returns necessarily cost a great deal in capital outlay and upkeep. The mere registering of the daily and hourly records required by the B.T. Rules in connection with them, costs time, labour, and outlay upon instruments.

With insulated returns all these special costs disappear. The rules for insulated returns are precisely the same as for insulated supply-feeders and line-conductors. The sections may be designed in accordance with the scientific principles of maximum commercial economy. The only B.T. restriction of which commercial considerations might suggest the abolition is the half-mile sectioning of the line-conductors.

16. In most double-track tramways there are now always two line-conductors, one for each track. The two are electrically connected so as to distribute, in some degree, extra heavy load arising in one over both. For each the maximum load may be taken as three cars in the half-mile at 30 ampères each, or 90 ampères. The usual size gives about $\frac{3}{40}$ square inch copper section. The largest size that has been used gives a section of $\frac{1}{8}$ square inch. Ninety ampères through $\frac{3}{40}$ square inch gives a current density of 1200 ampères per square inch. This is not at all excessive considering (1) that the maximum load occurs only seldom, (2) that it lasts a very short time, and (3) that the line is particularly well exposed to cooling influences. From the purely electrical point of view commercial economy would dictate a higher maximum current density and less outlay on copper. The section of the trolley wire is really dictated by mechanico-commercial considerations. The above size of section is needed for mechanical strength to resist the load due to the weight of the wire and wind pressure and weight of snow and ice. The factor of safety in the mechanical strength of the wire is, in fact, lower than it is usually imagined to be; and it is proved to be so by the too frequent breakages in storms. The element of load usually lost sight of is the storm-wind pressure exerted, not only on the surface of the bare copper wire, but upon that of a thick coating of ice or frozen snow over the wire. The diameter of this coating is sometimes in the case of telegraph wires three times that of the bare wire. Possibly it is never proportionately so large on tramway wires, but unfortunately the severest storm-winds are apt to occur when the wire is so covered.

The diameter could be made smaller if the span from pole to pole were reduced, but the extra cost of the extra poles, insulators, etc., might more than balance the copper saving. Up to the limit at which the wire section is electrically sufficient, the size of wire and span between poles ought to be designed so as to bring the cost of wire and poles together to a minimum, provided that this adjustment is not interfered with by one other consideration, namely, the impracticability of having more than a certain amount of sag in each wire-span. The spacing of the poles actually adopted ranges between 90 and 140 feet, and the sag between 10 and 18 inches.

This adjustment of span and section to minimize total cost could hardly be made with scientific accuracy, because the general objection to poles on æsthetic grounds is a substantial reason for increasing the span so as to diminish the number of poles, and it is an objection which cannot be evaluated quantitatively.

The design of the overhead line is dealt with more in detail in Chapter IV.

17. In designing the sections of feeders there is more opportunity to apply the principles of economy, first explained in this connection

by Lord Kelvin. As the principle is generally misunderstood and wrongly stated, it may be well to show its real nature by a very simple diagram. The diagram (Fig. 21) is general in its character, and the principle it describes applies, not only to conductors for electric transmission of energy, but also to numberless problems throughout the whole range of engineering.

In the diagram the horizontal ordinate S measures the size of plant of any kind used for the purpose desired to be attained, or any part of the whole plant which it may be possible to consider from the

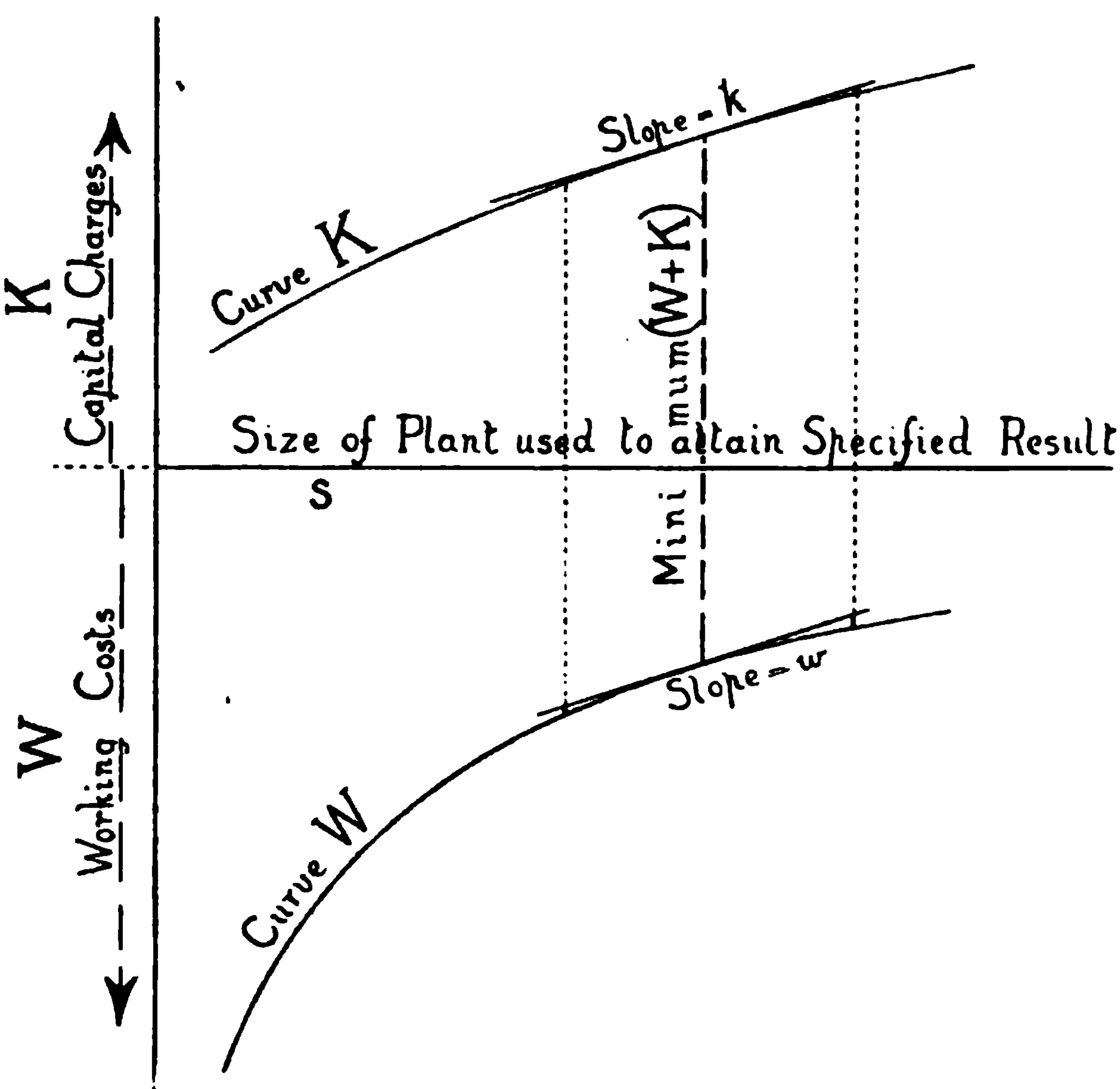


FIG. 21.

economic point of view apart from the rest. This size may be measured in many ways. In the problem of electric power transmission, it is convenient to measure it by the area of the copper section of the cables employed; this, at any rate, is the most convenient measure so long as the question in hand is that of selecting the best size of cable.

The capital outlay required depends upon many things besides the cable, but it increases with the copper section of the cable. If no other capital outlay were necessarily affected by change in this copper section, then a straight line would closely represent the relation between the copper section and the capital outlay, as the cost of

copper per hundredweight is nearly the same whether a large or small quantity be used. It is dearer for very fine wire than for large wire, because of the extra work per pound spent in drawing such wire; but within wide limits of large sizes the variation of price per hundredweight is small. Other parts of the cost, however, such as the insulation covering, the casing, trenching, and some other items, do not vary in the same proportion. Thus the diagram of relation of capital outlay to size of plant used is never a straight line, but is always a curve. It starts at some considerable initial height, slopes upwards, and has generally downward curvature, which is the curvature in the case now considered where S is the copper section used for electric power transmission.

This capital outlay is to be reduced to a running capital charge per unit of time—per year, or per day, or per hour. This reduction is effected by taking a yearly, or daily, or hourly percentage of the total outlay to cover interest and depreciation or sinking fund. The proper percentage is very different for the various items making up the whole, but an average covering the whole is usually struck. But it is an entire error to apply in solving the present problem the same average to the different sizes of plant, one of which is to be selected as the most economic, because a variation in size of only one part of the plant is contemplated. Much of the necessary outlay is unaffected by this variation, and only that part which is so affected need be considered at all. The curve K in Fig. 21, therefore, represents the interest and depreciation on that part alone of the whole outlay which is necessarily changed along with the size of copper section employed. This distinction between a part of, and the whole of, capital outlay is very important, because the depreciation on copper is very small. Thus while 10 per cent. is probably not too great for interest and depreciation on the total outlay on electric tramways, 4 or 5 is probably ample on the copper cables and what is necessarily varied with them.

The only object in increasing the size of section is to reduce the working costs. Part of these is the loss of energy in the transmission. This loss does not take the form of loss of current: approximately the same current is sent into the feeders at the central station as is delivered to the car-motors, and the amount that must be delivered is the same whether the conductors be small or large. The loss occurs in the form of drop of potential along the line. What is demanded is a specified quantity of current at a specified voltage between the terminals of the motor. The voltage between the + and − bus-bars at the central station must be higher than this by the product of the current and the resistance of the transmitting lines. In this product the current is not changed with the size of copper section, and the resistance is inversely proportional to this section.

The excess of central station voltage is thus proportional to the reciprocal of the cable section. Putting out of consideration, as unaffected, all the working costs that would remain if the transmission resistance were reduced to zero, the excess of voltage affects the total costs in two ways. First the boilers and engines have to work at a proportionately greater horse-power and consume proportionately greater fuel, oil, etc. Secondly, the dynamos to produce the higher voltage cost more to purchase, and thus increase the capital charges. The sum of these two increments of total cost is usually assumed as proportional to the excess voltage, and therefore inversely proportional to the cable section. It is taken per same unit of time as used in measuring K, and is plotted in Fig. 21 downwards from the horizontal base line to the curve W.

Now, evidently in Fig. 21 the vertical height between curve K and curve W at any ordinate S—that is, with the use of any size of cable—equals the excess of the sum of total working and capital costs over that constant part of this sum which is unaffected by the transmission losses and therefore by the cable section. At one size S this height between the two curves is a minimum, and this is the most economical size to employ.

To find the place in the diagram giving this minimum, which is marked by a vertical long-dash line, one good method is to run the vertical edge of a set-square along the horizontal T-square of the drawing-board and to set the dividers to the different heights between the curves. The approximate position of the least height is very easily found in this way. The method has two great merits: it proves the correctness of the result in the plainest and most convincing way to those who are not familiar with mathematical processes of calculation; and at the same time it proves that no such *exact* position exists—that is, the change of total cost is extremely small throughout a considerable change of section, and, remembering the imperfection of the data from which both curves have been constructed, it is clear that it is of no commercial importance to endeavour to find or to use the *exact* section determined by the calculation. This leaves latitude to suit minor considerations.

Fig. 21 shows that at this size of minimum total cost the two tangents to the two curves are parallel—that is, the slope k is the same as the slope w. Mathematically they are equal and opposite, or $w = -k$, because the ordinates to K are plotted upwards and those to W downwards. It is this test $w = -k$ that is deduced for a minimum or a maximum by the differential calculus. In the present case it is a minimum that results because of the curve K being flatter than the curve W, as is sufficiently indicated by the small heavy-line differences between the tangents and the curves shown on the short-dot verticals drawn in the diagram. If the curve K curved more

sharply than did W, then the test $w = -k$ would evidently reveal a maximum instead of a minimum. In the electric-conductor problem the curves K and W curve in the same sense (or in opposite senses if the ordinates be plotted on paper in the same direction instead of as here one upwards and the other downwards); and this makes the variation of total cost slow, and the determination of best section rather indefinite. If K curved in the other sense, the determination would be much sharper.

If the curve K be found so flat that it may be treated as a straight line, the point where $k = -w$ is easily found by drawing a tangent to curve W parallel to the straight line K.

Evidently the same solution would be found if the curves K and W were plotted so that their heights represented the total costs, including all those parts entirely independent of S. The inclusion of these would simply lift K higher, and put W lower, upon the paper without altering either their slopes or their shapes and curvature. It is upon the equality of the slopes that the fulfilment of the minimum conditions depends. The total heights do not enter into the problem.

The mistake of stating that the solution makes the total capital charges equal to the total working costs is constantly made. Lord Kelvin's original manner of stating the result is responsible for this error. Putting $K = kS$ (a straight line passing through the origin), and $W = \frac{\omega}{S}$, we have $w = -\frac{\omega}{S^2}$, and this equals $-k$, when $kS = \frac{\omega}{S}$ or $K = W$. It appears almost unfortunate that, according to these assumptions, this result of equality between capital and working costs emerges, so common and widespread is the misapprehension to which it has given rise. There is a case on record in which a "scientific" engineer proposed to increase the capital outlay in order to make it give a capital charge equal to the working costs without this extra capital expenditure having any chance of reducing working costs or having any possible influence upon them. Fortunately, another man, supposed to be "unscientific," and an ignorant dogmatist, interfered. If $W = W_0 + \frac{\omega}{S}$, then $w = -\frac{\omega}{S^2}$ still, and if $K = K_0 + kS$, the minimum of $W + K$ is still obtained from $k = \frac{\omega}{S^2}$, or $kS = \frac{\omega}{S}$. In this case $(W - W_0) = (K - K_0)$, or the extra part of the working costs influenced by S equals the extra part of the capital charges also concurrently influenced by S.

18. When the K curve is not much curved, as in Fig. 21, and the range throughout which it is sought to select the best size is not extremely wide, then the straight line $K_0 + kS$ may still be usefully

employed; but in place of expressing the result as a relation between the capital and working costs themselves, it is much safer to express it in terms only of the two rates of variation. From the above obtained criterion, $k = \frac{\omega}{S^2}$, there is obtained directly $S = \sqrt{\frac{\omega}{k}}$, or inversely $\frac{1}{S} = \sqrt{\frac{k}{\omega}}$.

It is evident that the two coefficients k and ω are each directly proportional to the distance or length of transmitting cable, and this length cancels out from the ratio $\frac{k}{\omega}$. That is to say, that the formulæ may all be taken per mile of this length, and the result $S = \sqrt{\frac{\omega}{k}}$ shows that the best section is the same whatever be the length.

If $\frac{\omega}{S}$ per mile be proportional to the ohmic energy loss in transmission, namely, to $\rho\frac{A^2}{S}$, where A is the current and ρ the resistance per mile for unit section, then $\omega = p\rho A^2$, in which p means the extra working cost per unit of energy so lost. The criterion for most economic section then becomes—

$$\text{Current Density} = \frac{A}{S} = \sqrt{\frac{k}{p\rho}}$$

= a constant density for each kind of cable,

$$\text{and Drop of Voltage per Mile} = \rho\frac{A}{S} = \sqrt{\rho\frac{k}{p}} = \text{a constant.}$$

In copper conductors this drop of voltage per mile, allowing a little for extra resistance at joints, is about 4½ volts for every 100 ampères per square inch in the current density. The economic copper current density varies from 250 to 600 ampères per square inch for tramway feeder transmission. In other electric transmissions with very low load factor it may be as much as 1000 and 1200.

Comparing different materials which may be used as conductors, copper, iron, etc., it happens that their specific resistance is roughly in inverse proportion to their cost per ton; so that there is little variation in the product ρk. Thus with correct economic adjustment there is about the same voltage drop per mile whichever material be used, and the current density is directly proportionate

to the cost of the material per hundredweight or inversely to its specific resistance.

19. Since this adjustment makes $k\mathrm{S} = \sqrt{k\omega} = \frac{\omega}{\mathrm{S}} = \mathrm{A}\sqrt{pk\rho}$, it gives the total cost per year, or other unit of time, and per mile of length, equal to—

$$\mathrm{K}_0 + \mathrm{W}_0 + 2\mathrm{A}\sqrt{pk\rho}$$

increasing in direct proportion to the average current required and to the geometric mean between the two rates of increasing cost p and k.

20. The constancy of the drop of voltage per mile resulting from this adjustment constitutes the main difficulty in adhering to it closely, because all the feeders start from the central station at the same potential, and they are necessarily of extremely different lengths; so that the rule would result in much smaller voltage between line and rail and between car-motor terminals at the more distant parts of the system. This it is particularly desired to avoid, because it leads to inefficient working of the motors, which are designed for one specified terminal voltage. And, in fact, the basis of the calculation was the assumption of a specified voltage at the motors, which are carried with the cars to all distances from the central station. Now the drop of voltage per mile is strictly proportional to the current density. If all feeders start at the same potential, and are required to deliver to the line all at the same potential, then the current density in each must be made inversely proportional to its length; which means that the volume and weight of copper in each is proportioned to the cube of its length. This clearly would make very long feeders excessively costly.

There are three methods whereby this difficulty may be combated, and the evil of excessive cost mitigated. All three are actually in use, and very frequently in combination.

In the first place, varying drop of potential at different distances is tolerated to a certain degree. In any case, it is unavoidable that the current drawn through each feeder should vary largely from minute to minute, according to the demand for power in starting, ascending grades, etc. The ohmic loss of voltage is thus unavoidably variable, and it is unavoidably accompanied by a corresponding variation of voltage across the terminals of each motor fed through that one feeder. The motors are thus forced to work on considerably different voltages at different times independently of change of distance from the central station. It is little extra disadvantage to be forced to work at such variable voltage at different distances from this centre.

21. In the second place, boosters are often inserted in the longer feeders, whereby the voltage at which they deliver to the line is kept up wholly or nearly to an equality with that of the shorter feeders. For a given drop in a long feeder, it is simply a question as to whether increase of copper section to the required amount or the insertion of a booster is the cheaper means of attaining the end in view.

22. Thirdly, the average length of low-tension feeders over a large district served from one generating station is made short by the use of a sufficient number of scattered sub-stations, the transmission from central to sub-station being at high tension, and the energy being transformed from high to low-tension at each sub-station. From 2000 to 5000 volts alternating, generally 3-phase, are used, with from 25 to 50 frequency. In the sub-station this is transformed in static transformers to low tension alternating of the same phase arrangement. The transformed current drives a synchronous alternating-current motor, or an asynchronous induction motor, mounted on the same shaft as a continuous-current dynamo, which supplies 500–550 volt current to the line direct, or to feeders leading to the line. The machine comprising the motor and the dynamo on one shaft is called a "motor-generator." A "rotary converter" is a similar machine for converting alternate to direct current, in which the motor and generator windings are combined. The "rotary converter" is gradually being superseded by the "motor-generator," which lends itself much more to facile control and regulation in its functioning, and to easy inspection and repair.

In high-tension transmission all the difficulties and irreconcilable impracticabilities of low-tension direct-current transmission nearly disappear. The voltage drop per mile corresponding to most economic current density becomes a small, unimportant percentage of the central voltage. With 300 ampères per square inch it is 13 to 14 volts per mile, and for 10 miles this is only $3\frac{1}{2}$ per cent. of 4000 volts. Moreover, the capital cost is raised in slight proportion only by decrease of current density, because the copper has become a relatively smaller item and the insulation a much higher item in this cost, while the cost of insulation increases slowly with increase of copper section.

As against the saving effected by the long-distance, high-tension transmission, there is to set off the introduction of all the sub-station costs. These are of two kinds. Firstly, there are the capital costs of the building and the plant of transformers and converters. Secondly, there are the running expenses of wages of attendance, lubrication, and the iron and copper losses in the transforming and converting plant. These are inevitable so long as low-tension direct current is insisted on upon the line and in the cars.

If P be the power in watts required to be delivered at a distance L, and at E voltage, then, for the sake of simple statement dealing with the problem as for direct current, the current is $\frac{\mathrm{P}}{\mathrm{E}}$, and the copper section is $\frac{\mathrm{P}}{\mathrm{E}}\sqrt{\frac{p\rho}{k}}$, if the economic current density $\sqrt{\frac{k}{p\rho}}$ be used. The E.M.F. required in the generator is $\mathrm{E} + 2\mathrm{L}\sqrt{\frac{\rho k}{p}}$, where the double distance 2L is used to provide for an insulated return of the same section as the outward cable. The power to be generated is this last multiplied by the current $\frac{\mathrm{P}}{\mathrm{E}}$, or—

$$\mathrm{P} + \frac{2\mathrm{LP}}{\mathrm{E}}\sqrt{\frac{\rho k}{p}}$$

The second term gives the extra power generated to balance the loss in transmission, and it is inversely proportional to E, as are also the section and weight of copper conductor. Multiplying this extra power by p, and the copper section by $2\mathrm{L}k$, there is found the total cost in capital charges and working expenses together of the transmission, namely, $\frac{4\mathrm{LP}}{\mathrm{E}}\sqrt{pk\rho}$. Thus the total cost of transmission is inversely proportional to E for fixed values of p and k. It is true that k, the cost per square inch copper section of the transmitting cable, is higher for E, say, 4000 volts, than for E = 500, and also that p, the cost per B.T. unit generated, is greater for the higher voltage in respect of the somewhat higher capital price per kilowatt of the dynamos and accessories. But $\sqrt{pk}$ for E = 4000 is not nearly so much as eight times $\sqrt{pk}$ for E = 500. It is only from $1\frac{1}{5}$ to $1\frac{3}{4}$ times as much.

There is, however, the sub-station additional cost to take into account if conversion to low tension be necessary. These add from 30 to 40 per cent. of the capital outlay on the central power station, thereby virtually raising the cost of the power supply per unit. The mean efficiency of the conversion in the sub-station ranges from 70 to 80 per cent. If it be taken as 0·75, this conversion necessitates the increase of the power to be delivered to the sub-station in the ratio $\frac{4}{3}$, the capital costs of the central station being correspondingly varied.

Thus the energy required to be generated at the central station is—

$$\frac{4}{3}\mathrm{P}\left(1 + \frac{2\mathrm{L}}{\mathrm{E}}\sqrt{\rho\frac{k'}{p'}}\right)$$

if P = energy required to be delivered from the sub-station, and if k' and p' be appropriate values for the transmission between central and sub-station, and if for this transmission the economic current density be used.

23. The capital outlay on sub-stations may equal as much as $\frac{4}{10}$ of that on the central station, which latter may give capital charges equal to $\frac{2}{10}$ of the total cost of power production. The total costs in the sub-stations have not so great a proportion to the capital charges as in the central station, and if the ratio be taken as two, the total sub-stations costs would equal about $2 \times \frac{2}{10} \times \frac{4}{10} = 0{\cdot}16$, or, say, $\frac{1}{6}$ of those of the central station. Taking those of the central station as equal to p' times the power generated in it, those of the sub-stations will equal—

$$\frac{1}{6} \times \frac{4}{3}p'P\left(1 + \frac{2L}{E}\sqrt{\rho\frac{k'}{p'}}\right)$$

Adding to this the costs of transmission, which are $\frac{4}{3}p'P \cdot \frac{4L}{E}\sqrt{\rho\frac{k'}{p'}}$, the total is—

$$\frac{4}{3}p'P\left(\frac{1}{6} + 4\frac{1}{3}\frac{L}{E}\sqrt{\rho\frac{k'}{p'}}\right)$$

If p' be taken $1\frac{1}{8}p$ and $k' = 1{\cdot}3k$, where p and k are the values appropriate to the smaller working voltage e, then the above becomes—

$$pP\left(\frac{1}{4} + 7\frac{L}{E}\sqrt{\rho\frac{k}{p}}\right)$$

This has to be compared with—

$$pP\frac{4L}{e}\sqrt{\rho\frac{k}{p}}$$

which would be the transmission cost at low tension e with a copper section giving the economic current density. It is easy to show that the former is less than the latter, provided the distance L exceeds a certain limit depending on the values of E and e. This limit is—

$$L > \frac{E}{\sqrt{\rho\frac{k}{p}}\left(16\frac{E}{e} - 28\right)}$$

Here $\sqrt{\rho\frac{k}{p}}$ is the economical drop of voltage per mile (L being measured in miles) appropriate to the low-tension direct transmission at e volts delivered.

In fully general terms this limit is expressed thus—

$$L > \frac{\sigma}{2} \cdot \frac{E}{2\epsilon v \frac{pE}{p'e} - (2 + \sigma)v'}$$

where ϵ = efficiency of sub-station conversion, σ = ratio of total sub-station costs to those of central station, and v and v' are the economic voltage drops per mile appropriate to the transmission tensions e and E.

To illustrate the effect of this limit take the economic drop of potential per mile as 15 volts.

Then the limiting length becomes—

$$L > \frac{E}{240\frac{E}{e} - 420}$$

If now $\frac{E}{e} = 8$, this is $L > \frac{E}{1500}$; and if $E = 4000$ with $e = 500$, then $L > 2\frac{2}{3}$ miles. Under the conditions specified, for distances less than $2\frac{2}{3}$ miles, low-tension generation and direct transmission at 500 volts at the delivery end is more economic; but for greater distances than this, it is more economic to generate and transmit at somewhat over 4000 volts, and to convert to 500 in sub-stations.

As a further illustration, take $\sqrt{\rho\frac{k}{p}} = 25$. Then the limit is—

$$L > \frac{E}{400\frac{E}{e} - 700}$$

If $\frac{E}{e} = 7$, this becomes $L > \frac{E}{2100}$; and if $E = 21{,}000$ and $e = 3000$, it becomes $L > 10$ miles.

The first example corresponds with street tramways in crowded cities. The second corresponds with a railway installation like that of Messrs. Ganz & Co. at the Valtellina in Italy, except that there the current is 3-phase throughout. The voltages at Valtellina are 20,000 in the transmission to the sub-stations and 3000 from these latter; and the sub-stations are placed between 7 and 8 miles apart.

The divisor $\left(16\frac{E}{e} - 28\right)$ becomes zero when $E = 1\frac{3}{4}e$. Therefore, unless E be made greater than $1\frac{3}{4}e$, no distance, however great,

will make the high-tension transmission cheaper than direct low-tension transmission.

When, on the other hand, $\frac{E}{e}$ is made very great, the limiting value of L equals very nearly $\frac{e}{16\sqrt{\rho\frac{k}{p}}} = \frac{e}{16v}$, or $\frac{1}{16}$th the ratio of e to the economic drop of voltage per mile in transmission at delivery tension e. For shorter distances than this, the direct transmission at e is always more economic, however high a tension E it may be proposed to substitute for it.

The following two tables, IX. and X., give the numerical results of the formula for the two values $e = 500$ and $e = 3000$ throughout a complete series of values of E :—

TABLE IX.—LIMITING DISTANCES L

FOR DELIVERY OF POWER AT TENSION $e = 500$ VOLTS

beyond which it is more Economic to Transmit

AT HIGH TENSION E WITH SUB-STATION TRANSFORMATION AND CONVERSION.

v assumed at 15 *Volts per Mile.*

E volts	875	1000	2000	3000	4000	5000	6000	∞
L miles	∞	16⅔	3·7	2·94	2⅔	2·52	2·44	2·08

TABLE X.—SIMILAR LIMITING DISTANCES L

FOR DELIVERY AT $e = 3000$ VOLTS

v assumed at 25 *Volts per Mile.*

E volts	5250	6000	10,000	15,000	20,000	30,000	50,000	∞
L miles	∞	50	15·8	11·5	10·2	9·1	8·4	7·5

It is easily proved that if the limiting length found by the above calculation for any particular conditions be called L_m, while the

actual length to be covered is L (greater than L_m); then the saving effected by transmission at higher tension equals—

$$\frac{4}{3} \times \frac{1}{6} p'P \frac{L - L_m}{L_m}.$$

or, in fully general terms—

$$\frac{\sigma}{\epsilon} p'P \frac{L - L_m}{L_m}$$

Fig. 22 sets out in diagram form the results given in these two tables.

24. In all the calculations explained above, the "load-factor" plays a most important part. All the capital costs run continuously throughout the year with little or no regard to the manner in which the time is utilized in doing work; the interest runs entirely so, and the depreciation is only partially and rather slightly affected by the

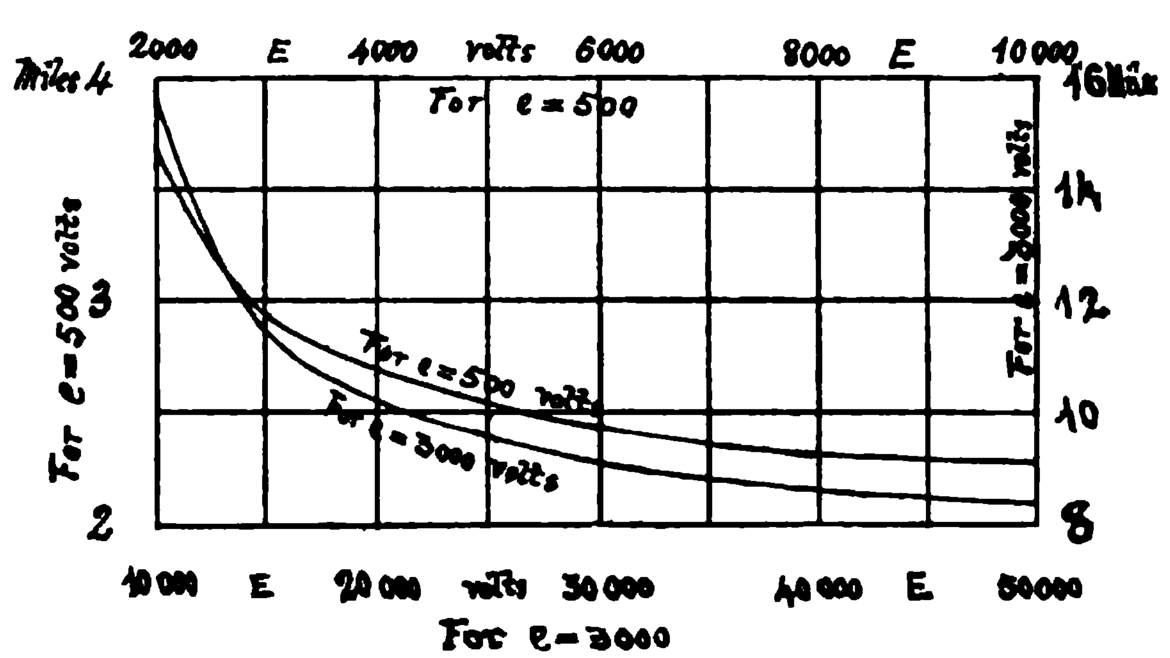


FIG. 22.

amount of use made of the plant. The capital value of the plant is based upon its full capacity when kept continuously at work on normal load. But the plant is not at work continuously, and, when at work, the load on it varies very greatly. The capital charges and the working costs must be reduced to one common measure before they can be added or compared per unit with the useful work done or the revenue earned. Either the variable work done must be reduced to an average uniform and continuous rate of working, or else the capital charge per unit of time must be converted to a variable rate following and covering the ever-changing rate of doing work. Again, a large portion of the working costs run on at a fixed rate without changing with the high or low rate of useful work.

The rate at which the plant has to work has a seasonal variation, illustrated in Fig. 8 of Chapter II. It has a much more marked diurnal variation, illustrated in Figs. 6, 7, 9, 10, and 11. The plant has to be of such size as to be capable of supplying the maximum demand made upon it. The yearly useful result, however, is proportional only to the average rate of working. The ratio between its actual average rate and the normal rate of which the plant is capable is called the "load-factor." Some engineers reckon the load-factor from the actual average rate over 24 hours per day—that is, the total work done per year divided by $24 \times 365 = 8760$ hours. Others reduce to the actual number of hours during which the plant is kept running; so that, if it be run 16 hours only per day, they would divide the work per year by $16 \times 365 = 5840$ to obtain the hourly average. Again, some would wish to compare this average with the full maximum possible overload capacity of the plant, while others prefer to compare with the normal steady load. There can be no doubt that the comparison with the maximum overload capacity is entirely wrong, as the plant is incapable of working steadily at this rate, so that, because of inevitable break-down, the proper annual rate of depreciation to associate with such a comparison would be *infinity*.

The other difference, although it changes largely the numerical value of the load-factor, is non-essential so far as scientific principle is concerned, if it be only distinctly understood that in computing capital charges per hour they must be deduced from the yearly charge by dividing by the same number of hours, 8760 or 5840, as is used in reducing the work done to an even hourly rate. An hour and a year are merely two different units of time, and all ambiguity is avoided by taking all quantities per year. The most rational form in which to define the load-factor is "the ratio of the actual amount of work done by the plant in one year to the amount it is capable of doing in one year without damage beyond the depreciation actually charged to its account, and making proper allowance for the time it is necessarily thrown idle for examination, cleaning, and repairs." The plant has to be designed of such size as to meet the maximum rate of working demanded at any time, and it is to this maximum rate that its full capacity and the yearly capital charges are proportioned; but these have to be spread over an actual amount of work less than this full capacity in the ratio of the load-factor. A material part of the working costs also are proportioned to the full capacity of the plant, and not to the lesser actual work it does. This part includes all of what are called "preliminary" working costs, such as that of getting up steam daily before work can be commenced.

Tramway work may be expressed in kilowatt-hours or Board of

Trade units, or, still better, in car-mileage. Let M be the actual car-mileage per year, and $\frac{M}{\lambda}$ the car-mileage that would be run per year if the full working capacity were kept up continuously, λ being the load-factor. Under favourable circumstances λ is from 30 to 40 per cent., so that $\frac{1}{\lambda}$ lies between $2\frac{1}{2}$ and say $3\frac{1}{2}$. The capital expenditure may then be written $K_0 + k_m\frac{M}{\lambda}$, where k_m lies somewhere between 1*s.* and 1*s.* 6*d.*, and K_0 seems to have values lying between £40,000 and £100,000. The annual capital charges for interest and depreciation, etc., may now be called $i\left(K_0 + k_m\frac{M}{\lambda}\right)$, where i is a percentage which ought not to range outside 6 to 10 or 11, but frequently appears in the accounts lower than 6.

For the present purpose of investigating the influence of the load-factor, the annual working costs may be expressed by the formula—

$$W_0 + w_m\frac{M}{\lambda} + wM = W_0 + \left(\frac{w_m}{\lambda} + w\right)M$$

Here w_m indicates the extra part of the working cost directly proportioned to the *maximum* rate of working, and w that part proportioned to the *average* rate of working, *i.e.* to the total work done per year.

Adding these together, and dividing by M, in order to arrive at the total cost per car-mile, there is obtained—

$$w + \frac{iK_0 + W_0}{M} + \frac{ik_m + w_m}{\lambda}$$

As an illustration, consider a case in which $K_0 = £50{,}000$; $k_m = 1s.\ 3d. = £\frac{1}{16}$; $i = 0{\cdot}08$; $W_0 = £2000$; $w_m = \frac{1}{2}d. = £\frac{1}{960}$; $w = 5d.$; and $M = 10^6$ miles. Then the cost per car-mile in pence is—

$$5 + \frac{6000 \times 240}{10^6} + \frac{1{\cdot}2 + 0{\cdot}5}{\lambda} = 6{\cdot}44 + \frac{1{\cdot}7}{\lambda}$$

If $\lambda = 0{\cdot}4$, this would equal $10{\cdot}7$; while if $\lambda = 0{\cdot}2$, it would be nearly 15. In this case the capital expenditure would be

$$£\left(50{,}000 + \frac{10^6}{16 \times 0.4}\right) = £206{,}250 \text{ if } \lambda = 0{\cdot}4,$$

and £362,500 if $\lambda = 0{\cdot}2$. In the first case, it is 4*s.* 1½*d.* per car-mile; while in the second case, it is 7*s.* 3*d.* per car-mile run.

As a second illustration, take $K_0 = £100{,}000$; $k_m = 1s.$; $i = 0{\cdot}08$; $W_0 = £5000$; $w_m = 0{\cdot}3d.$; $w = 4d.$; and $M = 10^7$ miles. Here the cost per car-mile in pence is—

$$4 + \frac{13{,}000 \times 240}{10^7} + \frac{0{\cdot}96 + 0{\cdot}3}{\lambda} = 7{\cdot}12 + \frac{1{\cdot}26}{\lambda}$$

If $\lambda = 0{\cdot}4$, this becomes 10·27; and with $\lambda = 0{\cdot}2$, it is 13·42. But $\lambda = 0{\cdot}2$ is an unlikely low load-factor in this case. With $\lambda = 0{\cdot}3$, it becomes 11·32.

Of the part that varies with the load-factor, 70 per cent. in the first example, and 76 per cent. in the second, is due to capital expenditure.

In the first example, 40 per cent. and upwards of the whole is affected by the load-factor. In the second example, this portion is 30 per cent. and upwards. It is in the part w that saving can be effected by the use of highly efficient plant, such as condensing in preference to non-condensing engines and double or triple expansion instead of simple engines. As the load-factor becomes smaller, such savings in w become of less and less comparative importance. A saving of 1*d.* in w would be about 10 per cent. of the whole if the load-factor be 0·4, but only 6 or 7 per cent. if $\lambda = 0{\cdot}2$.

25. As an illustration of one way in which a *small* or *gradual* alteration of the capital to be expended may effect a corresponding change in the working costs, the size of the boilers in the power station may be cited. If the boilers be small, they will need to be forced, and thus worked less efficiently than if of larger size. If there be an insufficient reserve of boiler power enabling all boilers to be thrown out of work in rotation for regular inspection and repair, the needful repairs will be overlooked and neglected, and when at last done, they will be found more expensive than if they had been taken in hand earlier, and also they will require to be run through hurriedly.

On the other hand, a difference of style of boiler, as, for instance, the choice between Lancashire and Water-tube boilers; or a difference of style of engine, as that between condensing and non-condensing, or between compound and triple-expansion; does not admit of a comparison between increase of capital charges and decrease of working costs by the method of small and gradual change. There is a gap, or *discontinuous* change, between the two sets of economic results.

In either case the already given diagram (Fig. 21) explains the principle of the endeavour to reach maximum economy. If K and W be corresponding capital charges and working costs taken per the same unit of time or the same unit of useful result, K_1 giving the

working costs W_1, and the greater K_2 giving the less working costs W_2; then, if $(K_2 + W_2)$ be less than $(K_1 + W_1)$, the greater capital outlay will be more economical. Converting the condition, it is also expressed as $(K_2 - K_1) < (W_1 - W_2)$, the increase of capital charge less than the saving in working costs. This is self-evident, and applies equally to discontinuous and to continuous alteration in design and method of working. But in the application of the rule, error is apt to be made in not reducing K and W to very strictly the same common measure—to a year's total results, or to per million B.T. Units utilized, or to per million car-miles run.

Up to some limit of capital expenditure—up to that below which niggardly expenditure injuriously interferes with proper working—the condition $(K_2 - K_1) < (W_1 - W_2)$ holds. Beyond some limit the additional capital expenditure becomes extravagant and ignorantly reckless. Here $(K_2 - K_1) > (W_1 - W_2)$. There is a long range between what simple unrefined common sense will recognize as niggardly on the one hand and extravagant on the other. Careful numerical calculations are needed to apply the test in order to obtain commercially useful results; and the minor items necessarily affected by change in the main features are so numerous, and constitute together so considerable a proportion of the total expenditure, that engineers and contractors who take "broad views," and do not trouble about exact estimates of details, are apt to get much out of true reckoning. This also offers a wide field of debate much taken advantage of by interested advocates of one or other style of construction.

If the change be *continuous*, then calling a very small $(K_2 - K_1)$ by the symbol dK, and the accompanying very small $(W_2 - W_1)$ by dW; then at the limit between advantageous and disadvantageous increase of capital, there is found $\frac{dK}{dW} = -1$. But, as previously explained, there is usually a useful range on either side of this limit, within which the advantage or disadvantage is so small as to be of no commercial importance. If K and W be plotted both as vertical ordinates in a diagram like Fig. 21, where the horizontal ordinate is S, any measure of size of plant; then the same limit may also be written $\frac{dK}{dS} = -\frac{dW}{dS}$, or $k = -w$.

If series of discontinuous changes have to be critically considered, then on either side of a certain limiting gap in the series, $\frac{K_2 - K_1}{W_1 - W_2}$ will be found to be less and greater than 1. When this place is found, there only remains to choose on which side of the gap to instal the plant. The choice will be determined by minor conveniences.

In applying this principle to the total costs per car-mile as affected

by load factor, K_0 and W_0 and i will have altered values for any entire change of style in the installation. For continuous or gradual changes, such as mere change of pressure or size of boiler, or number in a large series of boilers, or size or pressure or speed of engine, or moderate change of electric tension, then K_0, W_0, and i may be supposed to remain constant. On this assumption, the equation of the most economic relation of capital expenditure to working costs is, S again representing any particular measure of size or other feature of expense—

$$\frac{dw}{dS} + \frac{1}{\lambda}\left(i\frac{dk_m}{dS} + \frac{dw_m}{dS}\right) = 0$$

In tramway work, $\frac{1}{\lambda}$ being from $2\frac{1}{2}$ to $3\frac{1}{2}$, and i being, say, 8 per cent., this expression shows that the rate at which w varies is more important than that at which k_m varies in the ratio of 1 to from $0{\cdot}08 \times 2\frac{1}{2} = 0{\cdot}2$ to $0{\cdot}28$; *i.e.* in ratios from 5 to 3·6; and less important than that in which w_m varies in the proportion $2\frac{1}{2}$ to $3\frac{1}{2}$. Evidently the load-factor is very influential in determining the limit to which it is economic to push capital expenditure for the purpose of attaining higher efficiency in working.

26. There are three main methods in actual use whereby the expensive results of low load-factor may be mitigated. They may be mentioned in the order of the stages of the whole working process which they affect.

In the first stage, namely, that of raising steam in the boilers, Mr. Druitt Halpin's "Thermal Storage" has recently attained marked success. Fig. 23 illustrates this arrangement as applied to a water-tube boiler. Above the boiler is placed, horizontally, one or more hot-water storage cylindrical drums. The level of the water stored in these varies largely, sinking low when the boilers are supplying the maximum demand for steam. Above the water-level in the storage drum is a steam space kept in continuous open communication with the steam space of the boiler by a large-sized pipe between the two. Thus equality of pressure between boiler and storage tank is maintained at all times. The feed-water enters into the steam space of the storage drum. During hours of low demand for steam, instead of working the boilers at the lowest possible rate, they are worked at nearly normal average, and the excess of steam generated is condensed

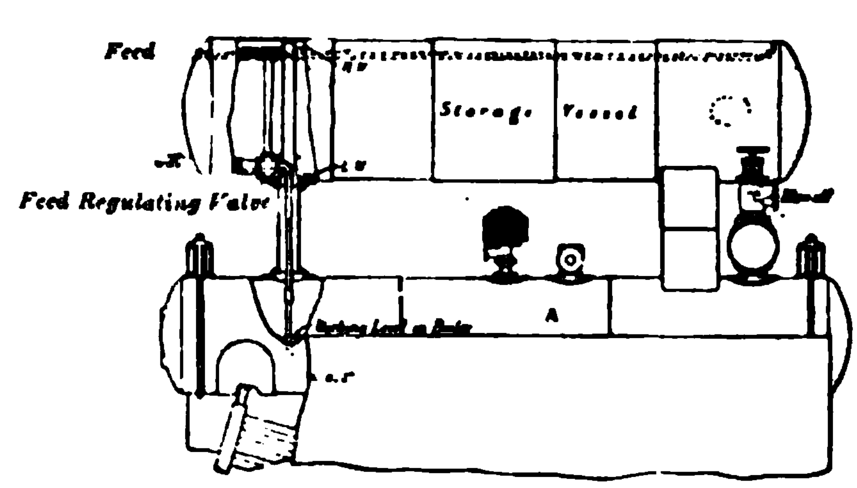


FIG. 23.

in heating the feed as it enters the storage drum. At these hours this feed is maintained at a rate somewhat above the normal. It is diminished, or cut off entirely, during the times of maximum demand for steam in the engines, and when, therefore, there is no furnace heat and no steam to spare for heating the feed-water. The boiler is fed at all times from the storage drum, and always with hot water at approximately steam temperature. During hours of small demand, the feed from drum to boiler is regulated to a slow rate of flow, while the feed into the drum is above average; so that during this time the level of water in the drum gradually rises, and heat energy is stored in the drum in proportion to the increasing quantity of water it contains. The level falls again during the hours covered by the peak or peaks of the load-curve, during which time the feed into the drum is checked, and the feed from drum to boiler is much above the average. In this way, at the Shepherds Bush Power Station of the Kensington and Notting Hill Electric Light Co., 2500 kilowatt-hours, or B.T. Units, are stored in 10 drums, each 24 feet long by 5 feet diameter.

The full volume of a drum 20 feet long by 4 feet diameter is about 250 cubic feet. If 0·8, or 200 cubic feet, of this is the volume between highest and lowest levels, the water filling this weighs 12,500 lbs. Taking the feed from a hot-well at 180° Fahr., and steam temperature at 380° Fahr., corresponding to 200 lbs. per square inch absolute pressure, the rise of 200° Fahr. gives $2\frac{1}{2}$ million Brit. Heat Units stored. Or, if the heating be from 180° to 340° Fahr., or 120 lbs. per square inch absolute pressure, the storage is 2 million Heat Units. Now, 1 kilowatt-hour, or Board of Trade Unit, equals 3400 Brit. Thermal Units. Thus, with the greater rise of temperature, the heat-storage per drum of this size is 735 B.T.U., and about 590 B.T.U. with the smaller rise of temperature. If this be converted to electrical energy in the efficiency ratio 0·15, the resulting equivalent electric-energy storage is $0·15 \times 735 = 110$ B.T.U. in the one case and 88 B.T.U. in the other.

When covered with the most suitable non-conducting clothing, the loss by radiation and air-convection from the storage drum appears to be very little. Mr. D. Halpin states that a consumption of 1 lb. of coal per hour is sufficient to balance the loss from over 200 square feet of radiating surface, or $1\frac{1}{8}$ lb. coal from a drum 9 feet long by 6 feet diameter.

In the storage drum the water does not, of course, quite reach an average temperature equal to that of the steam, but a test has shown that it fell short of it by only 3° Fahr.

Concurrently with the storage of energy, other incidental advantages are obtained with this system. The first of these is that, with proper arrangement, it is easy to get practically all the sludge and

the sulphate and carbonate of lime deposited from the feed-water in the storage drum, where it is thermally innocuous, leads to no risk of burning or wracking the plates, and from which also it is very easy to remove regularly. A catch-well, not shown in Fig. 23, is attached to the under surface of the drum for this purpose. This is an extremely important advantage, not only in lengthening the life of, and diminishing the repairs in, the boiler proper, but also in increasing its average heating efficiency, which falls very rapidly with the scaling and sludging of the heating surface. Another advantage is that the temperature in each part of the boiler is kept very uniform in time, and also very uniform throughout the whole water and steam space. When the feed is cold, injuriously large differences of temperature exist between the various parts, and the temperature at each part is apt to vary capriciously in time.

Along with these results there appears also a very large increase of heating efficiency and of steaming capacity. Two tests at different places agreed in showing over 20 per cent. increase in heating efficiency. But the increase of steaming capacity is in much larger ratio. Although only from $\frac{1}{8}$ to $\frac{1}{6}$ of the total heat required per pound of steam produced is put into the feed in the storage drums, it is reported that the addition of these drums has enabled the same boilers to generate from two to three times as much steam as they could without them, and the tests appear to be reliable. If this large claim be permanently established, it proves how great is the benefit derived from separating a complex process into parts—in this case into water heating and water evaporation—and accomplishing each part of the process in its own special compartment of the plant, each compartment being specially adapted to perform its own function. Numerous instances of the benefit accruing in this way are found in the history of engineering, and of other industries. It is the equivalent in automatic plant of what is called "division of labour" and "specialization" in human work.

27. This "thermal storage" relieves the boilers of the disadvantages of low load-factor. The stand-by running costs of a set of boilers working throughout much of their time at half or quarter duty are particularly severe. The thermal storage does nothing to mitigate the effects upon the engine and dynamo costs. The evils of low load-factor are not nearly so great in engines and dynamos as in boilers in respect of working expenses; but in respect of capital charges, they are equally, if not more, severe.

The mitigation of low load-factor upon engines and dynamos is accomplished by the use of accumulator secondary batteries. The cost of these is from £6 to £8 per B.T. Unit storage capacity. They can be used only with direct current. Thus with high-tension polyphase transmission from central power station to sub-stations,

the batteries are necessarily installed in the sub-stations on the direct-current side.

These batteries protect all the plant behind them from the evils of rapid and large fluctuation of output. They do not protect the direct-current feeders, the line-conductors, or the car-motors.

28. A third method of mitigation is, however, now being introduced on tramways. This has been termed the "Regenerative" system, and is being worked in this country under Mr. Raworth's patents. In this system the car-motors are so constructed as to act as dynamos during the slowing down of the train, and during the descent of steep inclines. In the first case, the kinetic energy, and in the second, the gravitation energy, of the car drives the motor-dynamo. It generates electric current energy, which it throws into the line-conductors, whence it is taken by other cars which are starting or are climbing steep gradients. Electric braking with direct-current motors was already introduced on the Rome tramways in 1896 by Signor Mengarini, and elsewhere.

CHAPTER IV

OVERHEAD TRAMS

1. The Glasgow Conversion from Horse Traction—2. Converted and Standard Cars—3. Leicester Cars, Reversed Staircases—4. Ventilation of Cars—5. Single-Truck Cars and Bogie Cars—6. Life-guards—7. Lighting of Cars—8. Single-deck Cars—9. Car Trucks—10. Bogie Trucks—11. Maximum Traction Truck—12. Car Motor Suspension and Gearing—13. Mechanical Stresses and Oscillations in Cars—14. Ditto in Motors and Gearing—15. Analysis of Mechanical Action in Driving—16. Car Motor Construction—17. Characteristic Motor Diagrams, and Electrical Action in Series Motors—18. Starting Resistances and Acceleration—19. Overcompounding of Central Station Dynamos—20. Series-parallel working—21. Controllers—22. Re-establishment of Equilibrium—23. Electrical Braking—24. Brakes—25. Analysis of Mechanical Action of Brakes—26. Skidding of Wheels—27. Current Collectors, Trolley Wheels—28. Bow Collectors—29. Roller Collectors—30. Line Conductors—31. Line Suspension—32. Span Wires, Rosettes, Poles—33. Points, Crossings, Frogs—34. Rails and Rail Bonding—35. Track Construction—36. Feeder Cables—37. Sub-station Plant—38. Central Station Plant—39. Central Station Switchboard—40. Central Station Costs—41. Depreciation—42. Capital Expenditure—43. Glasgow Statistics—44. Total Working Costs.

1. Up to now the vast majority of trams in America, the European Continent, Britain, and elsewhere are of the overhead line-conductor construction.

In describing the details of this construction, we will follow the Glasgow installation as our leading illustration. But where it is important to note variety of construction, there will be interpolated in the course of this description reference to and drawings of alternative designs in use in other towns at home and abroad.

The Glasgow system, like a great many others, has arisen by way of electrical conversion of previously existing horse-trams. This has necessitated the conversion to their new purposes of considerable numbers of buildings and of cars. When these have been bought by municipalities from private companies, as was the case in Glasgow, the prices paid have been for the most part based upon their utility as parts of a working horse-tram business. Thus the value of their special adaptation to this purpose was immediately lost, and the

capital expenditure was more than would have been necessary in starting *de novo* on the basis of electric traction. Where accounts have been properly handled, as in Glasgow, this has been followed by writing off as depreciation of these parts of the plant amounts which may appear excessive if the above be not remembered.

2. Fig. 24 gives a view of one of the Glasgow "converted" cars, while Fig. 25 shows one of the new cars. The converted car is, of course, put on a new underframe, and in this respect there is little difference between the two. In the bodies, by shortening the end

FIG. 24.—Glasgow Converted Horse Car.

platforms, a much larger interior accommodation is obtained in the new cars with the same total length over all. A single-deck car was also experimented with; but, as out of a total of 782 cars only 21 single-deckers have been built, it is proved that for heavy industrial city traffic like that of Glasgow double-deckers are essential. The standard (Fig. 25) is seated for 25 inside and 30 outside; and it is 28 feet long over all, the body being 17 feet, with 6-feet wheel-base and 30-inch wheels, and $4\frac{1}{8}$-inch axles. There is no roof to the upper deck, because the numerous railway bridges under which the cars have to pass do not leave sufficient headway.

The weight of each car unloaded, but with all motor and other electric equipment, is about 8 tons. The "spring-base" or length between the extreme points of spring suspension, is 14½ feet. Each car is, at night, lighted by 6 inside and 6 outside lamps, and bells are fitted at convenient positions throughout. The structural part of the body frame is built mainly of teak, and the roof beams of ash, covered with two layers of white wood and red pine, with heavily painted sailcloth interposed between them. Malleable cast-iron, wrought iron, and steel are used in the jointings of these parts; and steel angles are employed for the cross-bearers and the pillars of the platforms. The seats are made of narrow pitch-pine slats. No

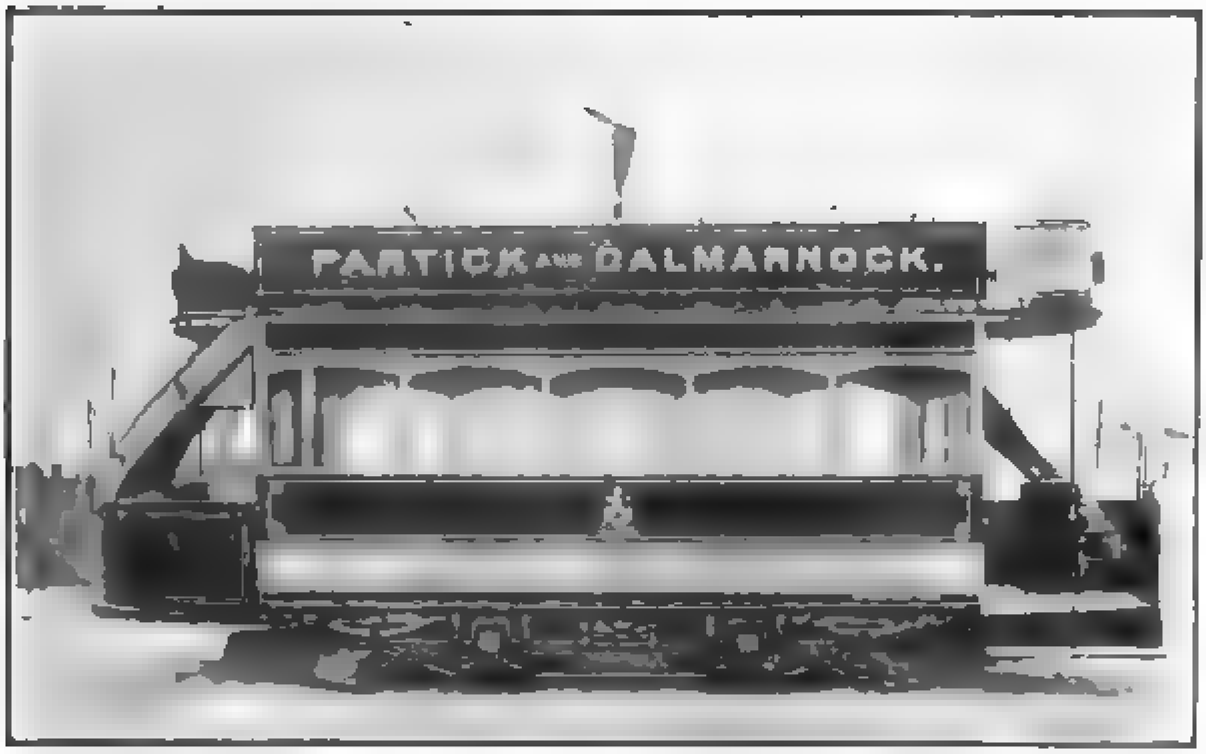


Fig. 25.—Glasgow Standard Double-Deck Car.

advertisements are placed in any parts of the car, and along the sides and ends of the top deck deep plain-coloured boards carry the local names of the routes travelled in very large letters. The colours of these boards indicate generally the district through which the route passes. "Destination boxes" are mounted at each end. These are seen in Figs. 26 and 29. Each box contains a roller, by turning which a placard is displayed bearing the name indicative of the destination towards which the car is travelling. The placards are translucent, and at night are illuminated by an electric light placed inside the box.

3. In Fig. 26 is illustrated one of the latest designs of Dick, Kerr and Co., as made for the Leicester Corporation. The staircases are

built on the now common "reversed" plan. On the ordinary staircase, the upward trend of which is mainly forward, if a passenger does not "hold tight" in mounting at the moment the car starts, his feet are carried forwards, while the upper part of his body, which does not directly receive the forward starting impulse, is left behind; and the consequence may be that he falls backwards down the stairs and is possibly thrown off the car. With the "reversed" staircase the upward trend is mainly backwards, and in starting the tendency

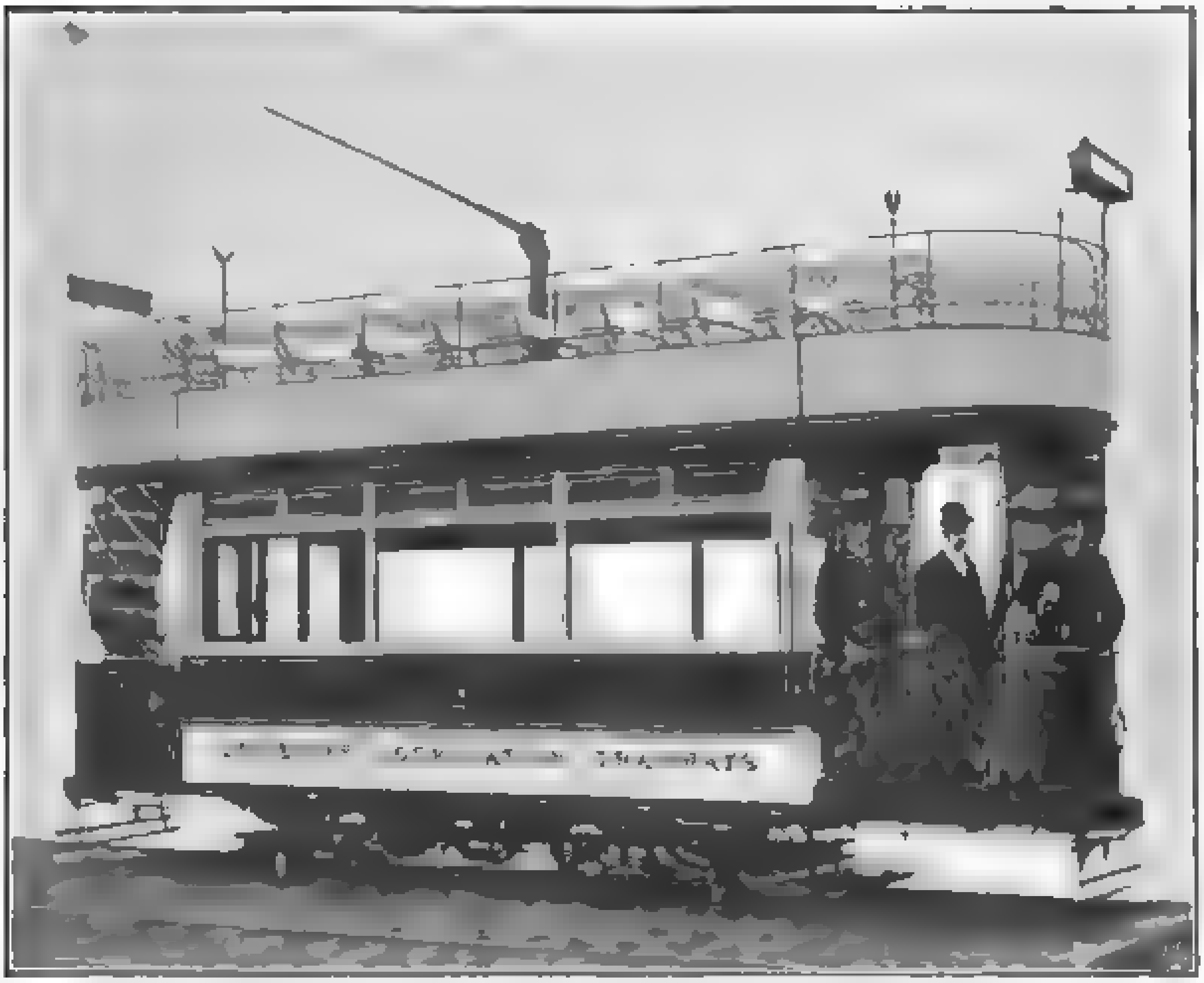


FIG. 26.—Leicester Double-Deck Car with Reversed Staircase, (by Dick, Kerr & Co.

is for the upper part of the body to fall towards the steps, calamity being prevented by the instinctive throwing out of the hands. A stumble on the stair may result, but in any case the passenger cannot be thrown off the car, because either the stair-steps or the rail-guard directly intervene to prevent this.

This car is seated for 22 inside and 34 outside, and weighs $7\frac{1}{2}$ tons or 300 lbs. per seat. It is of 16 feet body length, and $27\frac{1}{2}$ feet long over all. The extreme width over the roof is 7 feet, the width of floor-sills being 6 feet. The floor stands 25 inches above the rails,

and the ceiling is 6 feet 9 inches from the floor. The height from rail to top of trolley-post is 13 feet 2 inches.

4. Figs. 27 and 28 show the ventilation in these cars. When the small hinged windows A are in the vertical position no air is admitted.

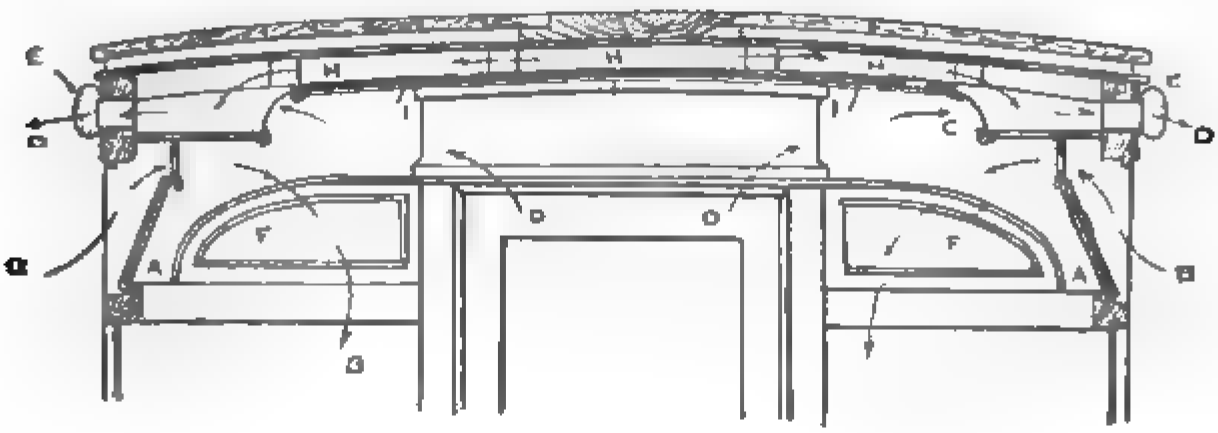


FIG. 27.—Ventilation of Car Roof.

When these are thrown into the inward slanting position, fresh air enters through the round holes pierced in the lattice above them, as indicated by the arrows B. Fresh air also enters at the ends of the cars by the windows F, hinged similarly to B, and protected outside from the entrance of rain by louvres. The vitiated air finds its escape through the pierced cornices CC, into the hollow space between the decoration millboard ceiling and the wooden roof, and thence by the non-return ventilator openings E. The hollow space H extends the full breadth of the roof, and the centre part of the millboard ceiling may be pierced so as to give additional exhaust passage into this hollow. The motion of the car produces a draught throughout the length of this hollow, which is so directed by the ventilators as always to extract air from the car and never to inject any.

FIG. 28.—Ventilation of Cars.

5. Figs. 24, 25, and 26 show what are termed "single-truck" cars, the whole running on four wheels mounted in one driving truck, and the axis of the car body always coinciding with that of the truck on which it rests. Fig. 29 shows a "bogie" car as built for the Cardiff Corporation by Dick, Kerr & Co. Here there are two trucks, generally both driving, which carry

the car under-frame by two turn-tables and two swivel bogie pins. The staircases follow straight transverse lines in the Cardiff car, and the platform is extended so as to give separate ingress for inside and top-deck passengers, and also room for the conductor, controller, and driver without obstructing the out and in passages. It is seated for 30 inside and 38 outside, the body being 22 feet long, and the over-all length $34\frac{1}{2}$ feet. The weight is $8\frac{1}{2}$ tons.

6. In Fig. 26 is seen distinctly the life-guard fitted at each end of the car. It consists of two parts. The front part is a hinged vertical screen of two stout laths. This is linked to the back part, which consists of a normally horizontal platform with vertical back, both

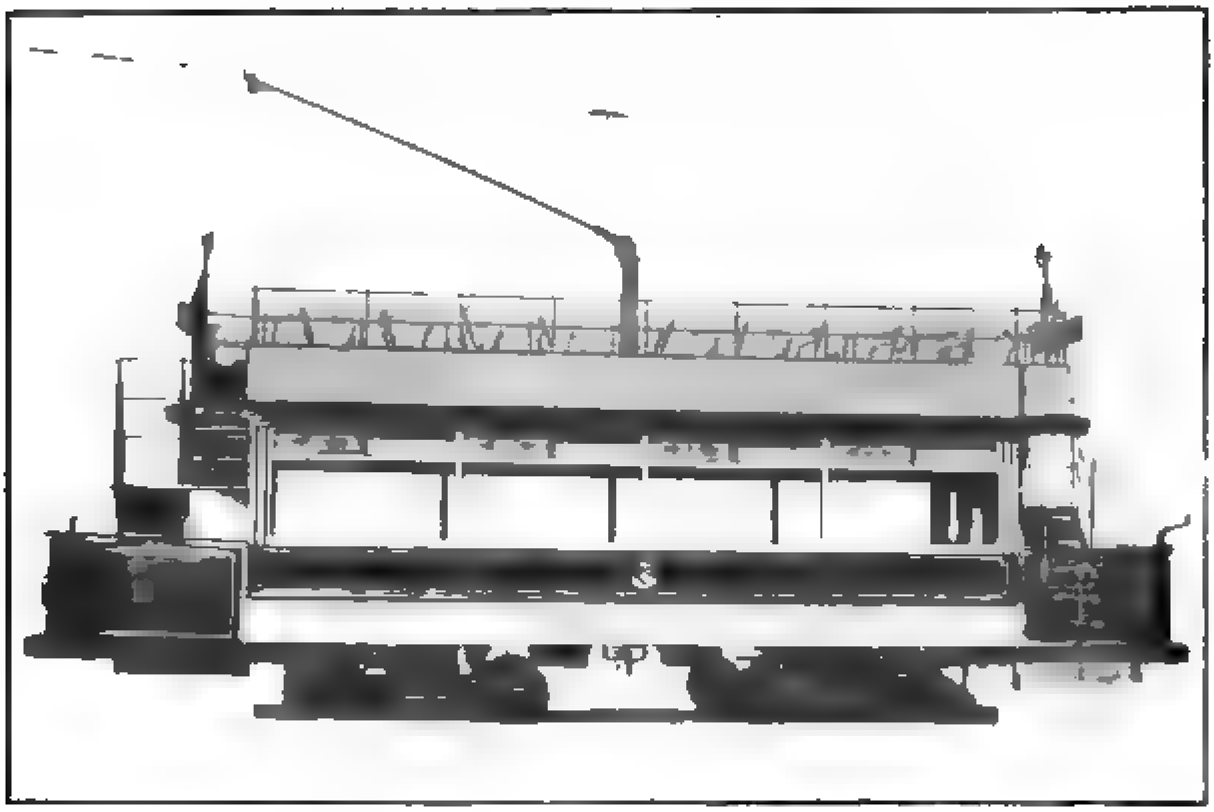


Fig. 29.—Cardiff Bogie Car.

made of similar wooden laths secured to a light steel hinged frame. When a body of any description falls in front of the car, it catches and throws backward the front screen, which, through the connecting linkage, lowers the front edge of the back platform. The fallen body rolls on to this, and is picked up by it and carried forward until the car is stopped.

In the Glasgow car (Fig. 25) the life-guard is of a different construction, somewhat like a bluntly pointed plough. It simply pushes the fallen body off to one side over the rail and clear of the following wheels. It is spring-mounted, so that when struck it drops close to the street surface, and thus prevents risk of small bodies getting

wedged between its under edge and the roadway or passing underneath its edge. This life-guard treats the fallen body more severely than does that shown in Fig. 26; but it contains no linkage which can get out of order, and, on this account, it is claimed that its saving action is more certain.

Another design of life-guard is a corded net upon a steel frame, which forms a bag into which the fallen body rolls. This form may possibly be more comfortable once one has got well into it, but the process of getting into it, on account of the sharp lines of the steel skeleton frame, can hardly be less painful than the operation of either of the other guards here mentioned.

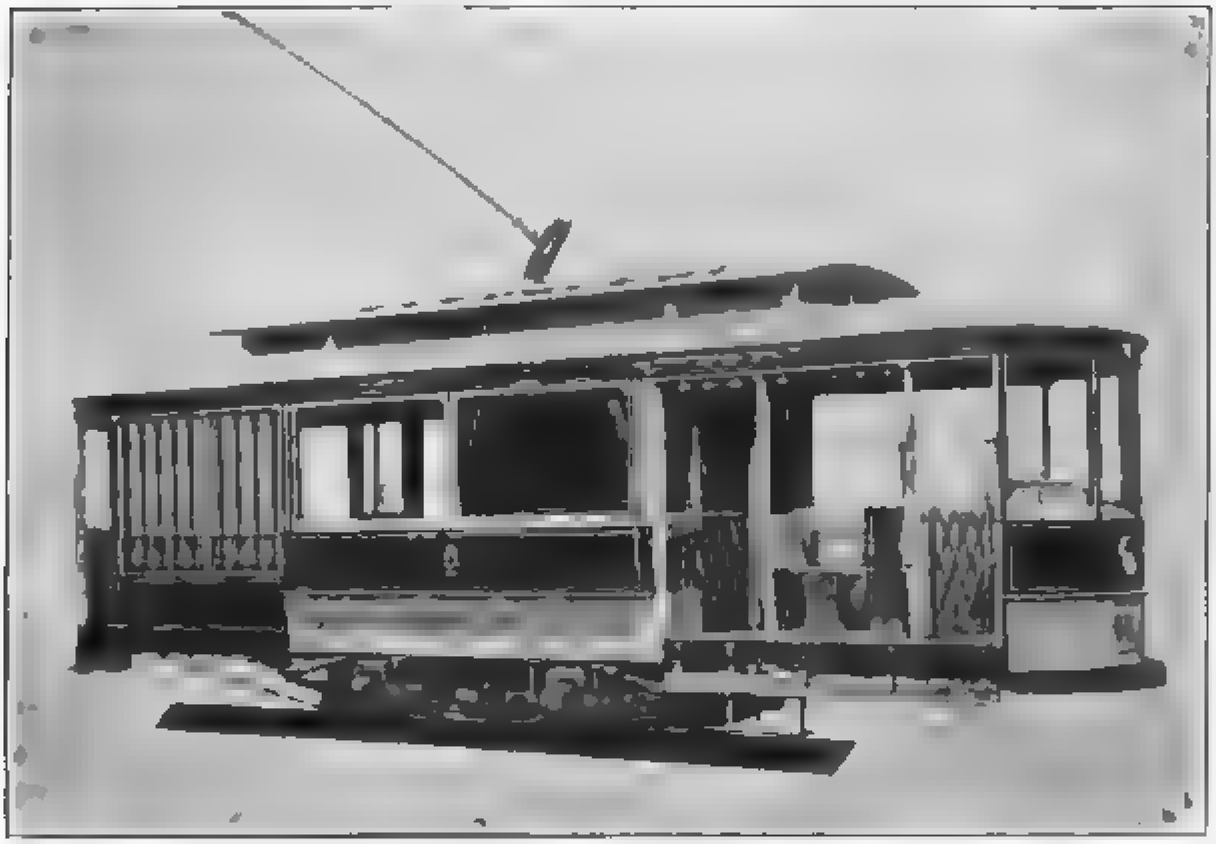


FIG. 30.—Single-Deck Single-Truck Car.

7. The efficient electric lighting of the cars is one of the main reasons why modern trams are so successful. Not only can passengers read with comfort at night in the cars, but they are free of the smells accompanying oil lamps. If horse omnibuses had installed accumulator battery electric lighting, had adopted decent inside ventilation, and had improved their spring-suspensions—three reforms easily accomplished—they would have made a much better fight against tramways.

8. Figs. 30 and 31 illustrate single-deck car construction. The first is on a single-truck, and is seated for 34 persons, 16 inside and 18 outside. These cars, half of which are open to the weather, are

termed "combination" cars. The open portions are protected by windowed storm-screens and sun-blinds. Fig. 31 is a "bogie combination," seated for 56, 24 inside and 32 outside. These are sometimes furnished with hinged steps controlled through a linkage and

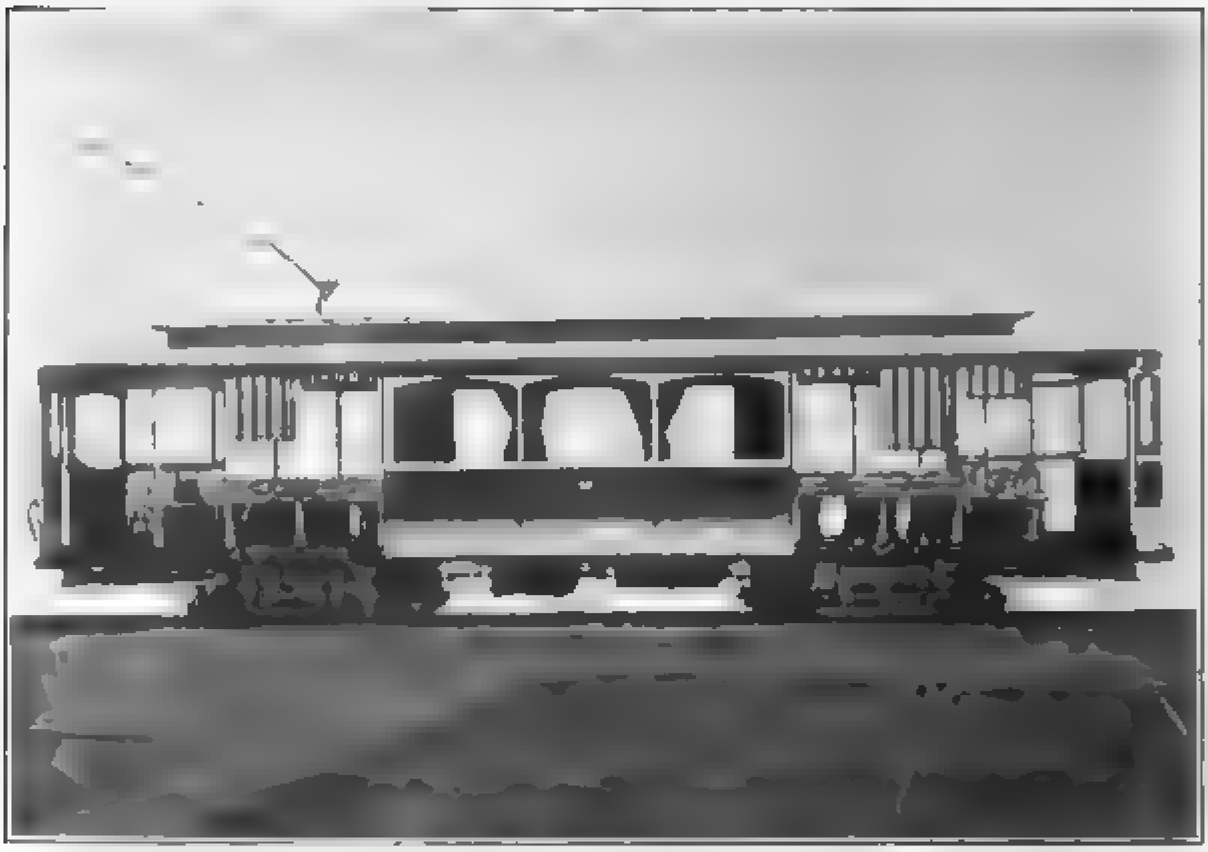


FIG. 31.—Single-Deck Bogie Combination Car.

lever by the conductor, who turns them up and so prevents any one trying to get in or out when the car is in motion. In some modern construction, however, this is prevented by sliding hinge-lattice gates, as in the front part of Fig. 30.

9. The Glasgow single-truck consists of two heavy forged steel

FIG. 32.—Truck Side-Frame-Bar.

bars bound together by four transverse beams. The two end-beams are called "sills." Such a truck side-bar is shown in Fig. 32. The two arched parts are called "yokes." The inside cheeks of these form the horn-plates, in which the axle-boxes are free to slide

vertically. The main portions of these bars have, in the Glasgow cars, a section 4 inches deep by 2½ inches thick.

Fig. 33 shows the Brush Co.'s design of single-truck with two motors mounted in place. It will be seen that the side-bars hang upon the axle-boxes by very short (9 inches) plate-springs, these boxes bringing the load upon the axle-journals, and through them upon the wheels. Because of the shortness of these plate-springs, the truck-frame, which carries the hinder part of the motor, has a very

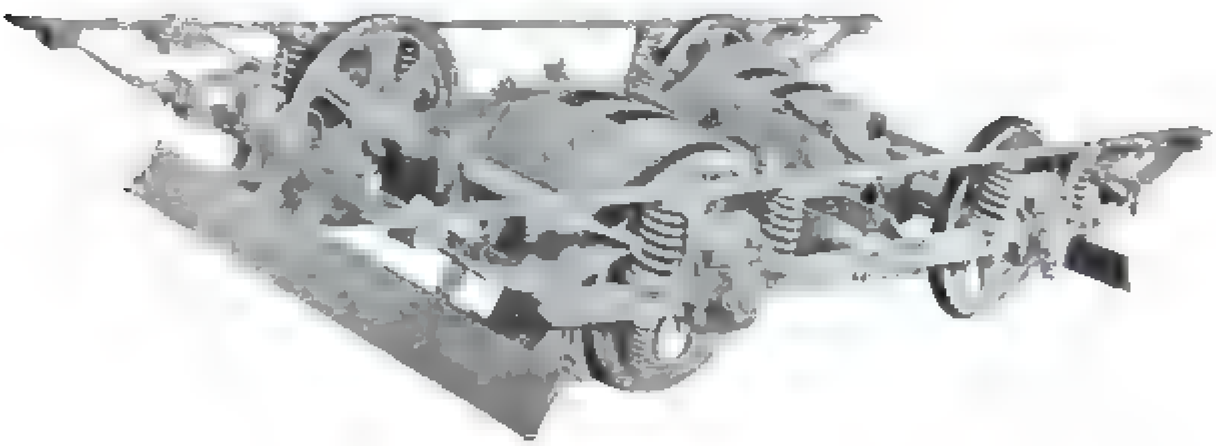


FIG. 33.—Brush Co. Two-Motor Single-Truck.

small range of spring motion over the axles. Each heavy side-bar supports a light top-bar by eight springs, and the car body is bolted to the two top-bars thus suspended. The weight of the car body and its passenger load being thus distributed between sixteen springs, each of these can be made very flexible. The two pairs of springs adjoining the horn-plates are cylindrical coils. These are pure load-carrying springs. At the front and rear ends are plate-springs of the type termed "three-quarter elliptical," each giving two points of spring support. These both carry load and also transmit the horizontal forward driving forces, as well as the backward horizontal forces

FIG. 34.—Dick-Kerr Single-Truck.

involved in braking. The car body has no lateral guidance except through these sixteen springs, and is thus given an easy side roll as well as vertical swing.

Fig. 34 shows a somewhat different truck design by Kerr & Co. It is approximately that used in Glasgow. Here the side-bars hang

upon the axle-boxes by means of two stout coil-springs bearing upon spread horn extensions of the outside ends of the boxes. On each side, the top-bar to which the car body is bolted is carried by the side-bar through four coil-springs and two plate-springs, each of the latter furnishing two points of spring support. The horn-plates are stiffened by their lower ends being tied together by a horizontal bar bolted to them, and this bar, being extended to join the two pairs of plates, increases the beam strength of the side-bar by virtually increasing its depth.

Fig. 34 shows two motors in place on the truck, the inner end of each motor casing bolted to a cross-beam, which is carried at each end by coil-springs. These springs deliver their thrust to the heavy frame side-bar. The other end of the motor is slung upon the axle, and the weight of the motor is divided between the axle and the hinder spring support on the side-frame.

10. A bogie truck of Brush Co. construction is shown in Fig. 35.

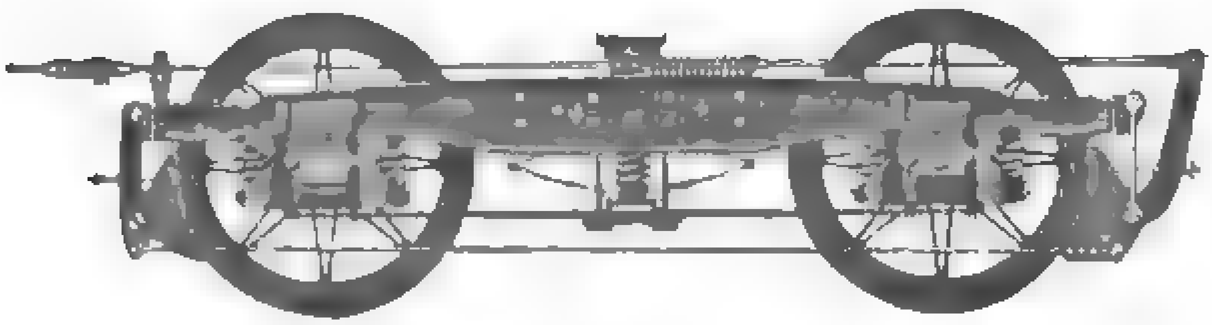


Fig. 35.—Brush Co. Bogie-Truck.

Here the frame side-bars are of cast steel, and at each end these are strongly braced together by transverse steel beams or "sills." The frame is borne by the axle-boxes through four coiled springs as in Fig. 34. On the end sills stand four spiral springs carrying two cross-beams, not shown in the illustration. To these beams are bolted angle-plates, upon which rests a considerable portion of the weight of the car body, but which are not screwed or otherwise fastened to the car body. To the under-frame of the car body is attached the bogie-pin which rests in the foot-step seen in the centre of the truck. This foot-step is formed in what is called the "bolster," which rests on springs. This bolster is capable of sliding vertically and through a small horizontal transverse range in the truck frame; but it cannot move in this frame forwards or backwards, being confined between two deep parallel vertical transverse plates bolted to the side-bars, these plates forming a "housing" or guide for its vertical and transverse oscillation. The springs carrying the bolster rest upon a swing frame hung from the main truck frame by swinging links. At each end of the bolster is a horizontal plate, on which

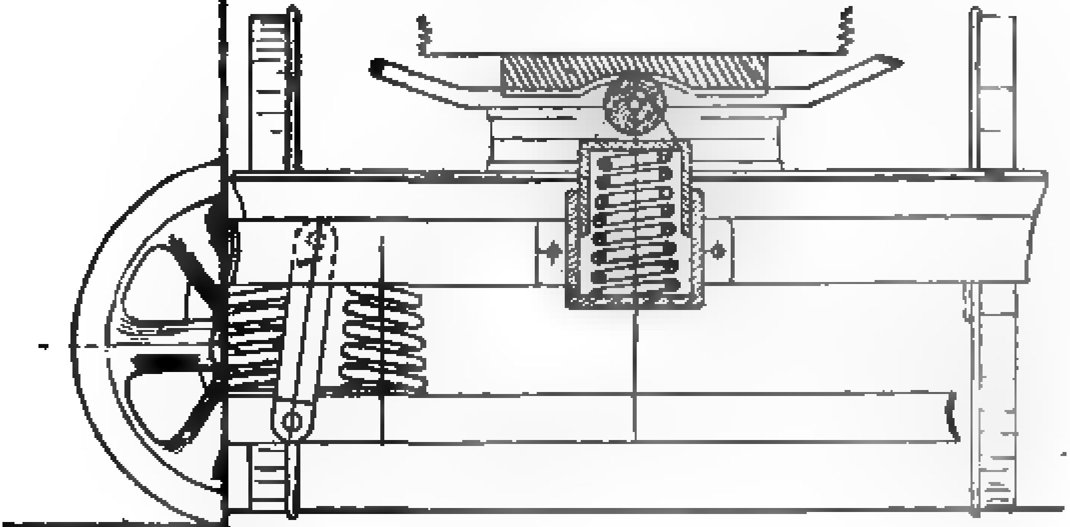
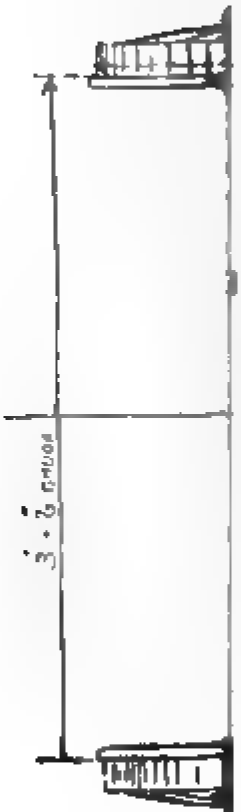


FIG. 86c.



Maximum Traction Truck with Adjustable Traction Attachment.

[*To face p.* 99.

rests part of the weight of the car body. These two plates and the two plates on the end sills together form what is virtually a turn-table, on which the car body rubs in swivelling round the bogie-pin. The construction of very similar bogies for electric railway plant is described more in detail in subsequent chapters.

11. Figs. 36A, B, and C illustrate what the Brush Co. call their

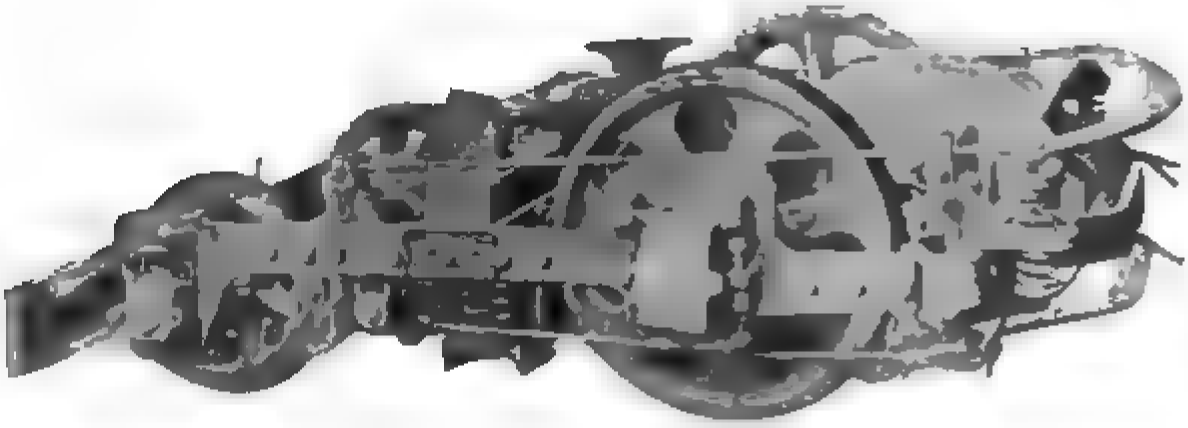


FIG. 36.—Brush Co. "Maximum-Traction" Truck.

"maximum traction" bogie truck. This can have one motor only mounted upon it, which drives the larger pair of wheels shown. The smaller pair are called "pony" wheels. They are at the leading end of the truck, and carry much less than half the load. The greater load thrown on the driving-wheels gives them greater adhesion on the rails, and enables a more powerful motor to be utilized on the one axle. The proportion of the load thrown on the drivers in this construction of truck can be greatly increased by a device shown in Plate Fig. 36A. The bogie-pin delivers none of the load to the bolster. The plate fastened to the car-body under-frame and to which the bogie-pin is secured, lies upon another plate which forms a sort of bracket extension of the bolster. A spring-borne roller is introduced beyond the bolster to take part of the load and thus permit easy transverse sliding on the bolster. Thus the swivel centre, which is made to approximate to the resultant centre of load as distributed over the five bearing surfaces, is removed away from the bolster to nearly over the driving axle.

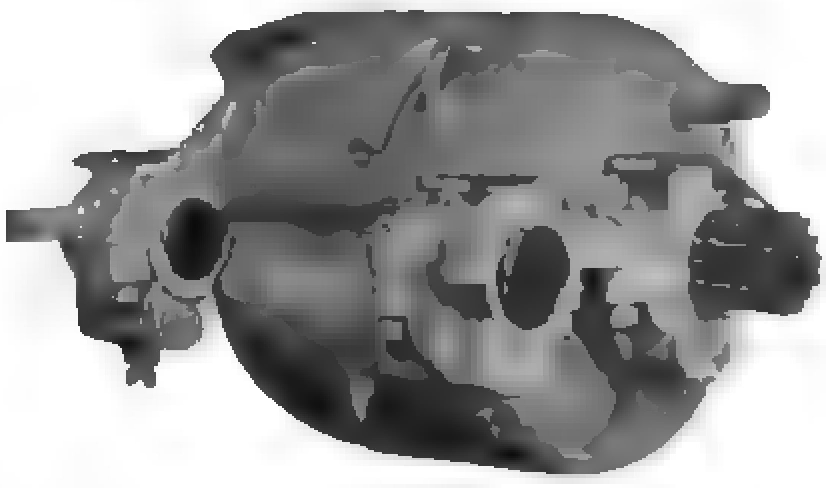


FIG. 37.—Brush Co. Tram-Motor.

12. Figs. 37 and 38 illustrate two different tramway motors by the Brush Co. and Dick, Kerr & Co., and enable one to understand how it is slung in the truck. Through the two bearings in the front of Fig. 37 passes the main driving axle, upon which the running wheels are keyed and upon whose end journals the axle-boxes between the horn-plates of the truck rest. This part of the motor casing is thus supported directly by the axle at these two bearings. The casing contains two other bearings carrying the shaft of the armature, as best seen in Fig. 38. The armature shaft and the wheel axle are geared together by a pinion on the former and a spur-wheel on the latter. The casing is made in halves, loosely hinged together behind the armature, so that it may be opened for inspection and repairs of the armature and field-magnets. When closed, the halves are bolted together in front of the axle-bearings and behind the armature-shaft bearings, the closure depending in no degree upon the hinge. Cross-beams behind the casing carry the major part of the weight of motor and casing through the intervention of springs, and deliver it to the side-bars of the truck frame.

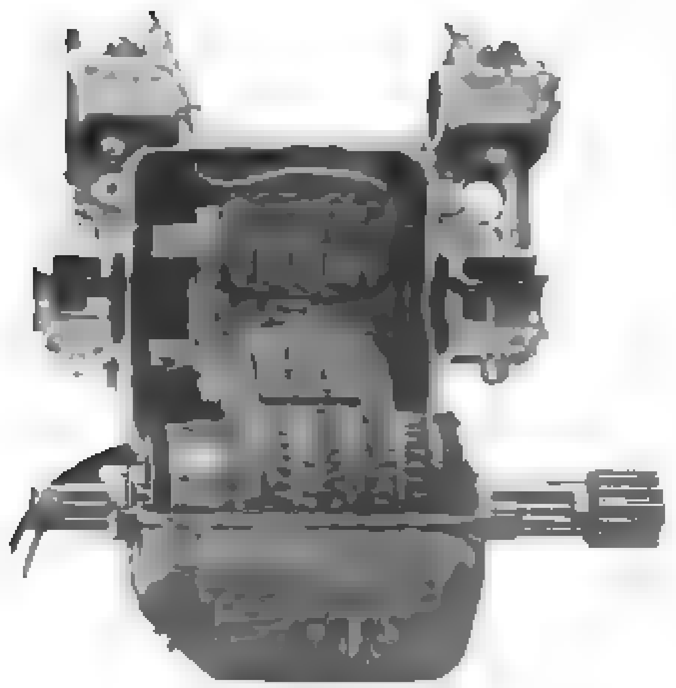


Fig. 38.—Dick-Kerr Tram-Motor.

13. The construction of the electrical parts of the motor will be referred to presently. Meanwhile its mechanical action and the mechanical actions of the spring suspensions throughout the truck may be best explained here.

If, when any load rests quietly upon a spring of any sort, it produces a deflection, D, upon that spring; then any "free" or "natural" oscillation of that load upon the spring will take place about the position defined by D as central position, and the ratio of the velocity—acceleration towards this centre to the displacement is $\frac{g}{D}$, where g is gravitational free acceleration, or 32·2 feet = 386 inches per second per second. From this it follows directly that the time period of a complete natural oscillation is $2\pi\sqrt{\frac{D}{g}}$, or

$$\text{T in seconds} = 0{\cdot}32\sqrt{\text{D inches}}.$$

For the deflections 1 inch to 6 inches, the following are the periods of natural oscillation, and the distances the car travels during one complete swing when running at 10 miles per hour.

	D inches	1	2	3	4	5	6
	T second	0·32	0·45	0·555	0·64	0·715	0·8
Distance travelled in T second at 10 miles per hour	feet	4·7	6·6	8·2	9·4	10·5	11·8

This period and the travelling length of one complete up-and-down swing is seen to depend solely upon the deflection of the supporting spring or springs under quiet loading. If for heavier loads the springs be made proportionately stiffer (not simply stronger), so as to leave the deflection the same as for lighter loads, the period of oscillation will remain unchanged. But with different loads upon one and the same set of springs, the period increases as the square root of the load, because the quiet deflection increases in proportion to the load. It is difficult and unusual in tram-cars to provide for more than 3-inch deflection, and the length of the running wave in the natural oscillation is between 6 and 8 feet. It is worth noting that the substitution of a larger number of correspondingly weaker springs makes no difference in the result.

When a wheel becomes unequally worn, each revolution produces a tendency to set up oscillation, and the distance travelled per revolution by 30-inch wheels is about 7 feet 10 inches. This is very near the length of wave for $2\frac{3}{4}$-inch deflection springs, and either a larger or smaller spring deflection should be used if it be not determined to maintain the wheels very true by frequent re-turning.

The wheels follow the irregularities of the rail-surfaces very closely, the reason for this being that the force with which they are pressed towards the rails is greater in a very large proportion than the weight of their own mass, the load upon them being from ten to fifteen times their own weight. Thus when a wheel jumps from the rail for the fraction of a second, it falls towards it with an acceleration ten to fifteen times as great as gravity, that is, say $12\frac{1}{2} \times 32, = 400$ feet per second per second. Thus it would fall $\frac{1}{4}$ inch in about $\frac{1}{100}$ second, corresponding to a length of travel of $1\frac{3}{4}$ inch at 10 miles per hour; or fall $\frac{1}{8}$ inch in $\frac{1}{140}$ second during $1\frac{1}{4}$ inch forward travel. This latter is in excess of the jumps made at the worst worn unequal tramway rail joints. Thus the jerks caused by rail inequalities may be regarded as almost instantaneous in comparison with the long natural swing of the car body. Taking $\frac{1}{10}$ inch as the maximum sudden deflection caused in this way, and 3 inches as the deflection of the body-springs under quiet load, then the maximum vertical

acceleration caused in the car under-frame by such jerks is $\frac{1}{30}\,g$, or one-thirtieth of that due to free gravity fall. The average during the up stroke of the jerk from mean position is about half of this; and during the down stroke as far as this mean position, there continues an *upward* acceleration of the mass lying above the springs, the mean of which is the same as on the up stroke. These accelerations due to the sudden and short-lived jerk are superadded upon whatever acceleration may at the moment exist in the long-swing natural oscillation.

If d be the semi-range of the jerk of the wheel above mean position corresponding to D spring-deflection, then the mean vertical acceleration due to the jerk during the up and return pitch of the wheel is $\frac{d}{2D}g$, and the mean accelerating force is $\frac{d}{2D}W$, where W is the load on the springs.

The work done during and by such a jerk must not be calculated by multiplying this mean force by the motion d. In the first place, the working force is not the above, but the whole mean force exerted by the spring, namely $\left(1+\frac{d}{2D}\right)W$, and the work done by this force includes the lifting of the load W. In the second place, the work done from below upon the springs during the up-throw is mostly spent in storing elastic energy in the springs, which is restored on the down stroke mostly in driving the wheel downward again with the very quick acceleration already explained. During the jerk the work done on the mass lying above the springs depends on what vertical movement that mass makes during the jerk, and this depends entirely upon the phase of its long natural swing at which the jerk occurs. The time of the jerk is so small in comparison with the whole period of the long swing, that the velocity of the heavy mass may be taken as nearly uniform throughout the jerk. The change of velocity caused by the jerk may be in the same, or in the opposite, direction to the momentary vertical velocity. When in the same direction, the oscillatory kinetic energy of the load on the springs is increased; when in the opposite direction, it is decreased. In the first case the amplitude of the long swing of the car body is increased; in the second case the jerk decreases the previously existing amplitude.

Put in exact algebraic terms, the above is expressed as follows, the calculation ignoring a couple of terms of no real importance, and the duration of a jerk being assumed as equal to the time taken by a wheel to fall freely a depth, d, under the acceleration due to the whole load, W, upon it. The weight of the wheel and the part of axle, etc., moving along with it is called w. Gravity acceleration is called g. The velocity in the long swing at the moment of the jerk is called V. r, also, is the name given to the vertical semi-range of the long swing of the car body.

Then the—

$$\text{Duration of one jerk} = \sqrt{\frac{2w}{g\text{W}}d};$$

and—

$$\text{Change of velocity in W due to one jerk} = \frac{d}{\text{D}}\sqrt{\frac{gw}{2\text{W}}d}.$$

If this change be in the same direction as V, then—

$$\text{Increase of kinetic energy in W due to one jerk} = \text{V}\frac{d}{\text{D}}\sqrt{\frac{\text{W}w}{2g}d};$$

and—

$$\text{Increase of semi-range of long swing of W} = \text{V}\frac{d}{r}\sqrt{\frac{w}{2g\text{W}}d};$$

and—

$$\left.\begin{array}{l}\text{Increase of maximum velocity-acceleration at top} \\ \quad\text{or bottom end of the range of the long swing} \\ \quad\text{of W}\end{array}\right\} = \text{V}\frac{d}{r\text{D}}\sqrt{\frac{gw}{2\text{W}}d}.$$

The last quantity is the most directly important, as it is upon it that the discomfort of the swing to the passengers is proportional. The effects of successive jerks are cumulative so long as they continue to give the product of V and the change in V of the same sign; but they partially neutralize each other when the successive jerks give opposite signs to this product. As the jerks occur mainly at the rail-joints, it is important that the rail-length should not be approximately a multiple of the travelling length of a long natural swing at the normal full speed of the car.

A high value for $\frac{w}{\text{W}}$ is 0·08. Inserting about 0·078 for this, and the usual value of g = 32·2 feet = 386 inches per second per second, these formulæ reduce to the following, where all dimensions should be measured in inches, seconds, and pounds—

$$\text{Duration of jerk} = \tfrac{1}{50}\sqrt{d}$$

$$\text{Change in velocity of W} = 4\frac{d}{\text{D}}\sqrt{d}$$

$$\text{Increase of kinetic energy in W} = \tfrac{1}{100}\text{VW}\frac{d}{\text{D}}\sqrt{d}$$

$$\text{Increase of semi-range of swing of W} = \tfrac{1}{100}\text{V}\frac{d}{r}\sqrt{d}$$

$$\text{Increase of maximum acceleration of W} = 4\text{V}\frac{d}{r\text{D}}\sqrt{d}.$$

For example, if D = 3 inches and $d = \frac{1}{9}$ inch, these reduce to—

$$\text{Duration of jerk} = \tfrac{1}{150} \text{ second;}$$
$$\text{Change in velocity} = \tfrac{1}{20} \text{ inch per second;}$$
$$\text{Increase in kinetic energy} = \frac{VW}{8100} \text{ inch-pounds;}$$
$$\text{Increase in semi-range of swing} = \tfrac{1}{2700}\frac{V}{r} \text{ inch;}$$
$$\text{Increase in maximum acceleration} = \tfrac{1}{20}\frac{V}{r} \text{ inch per second per second.}$$

14. In the motor the field-magnets exert an almost perfectly uniform torque upon the armature, except during starting; that is, any considerable change in torque is spread over very many revolutions of the armature. This uniform torque exerts a correspondingly uniform pressure between the teeth of the pinion and those of the spur-wheel upon the driving axle. The resistance to driving is not similarly uniform; it is subject to sudden change from change of wind and rail resistance. Fortunately these changes of resistance do not react upon the spur-gearing; otherwise this spur-gearing would not have nearly so long a life as it actually has. The momentum of the car as a whole operates with a fly-wheel action overcoming these changes in resistance. The changes due to sudden wind-gusts are absorbed directly in the body of the car. Those due to rail inequalities react upon the wheels, axles, and axle-boxes, but they are transmitted no further than this through the rotating machinery. At the axle-boxes they are absorbed by the horn-plates, through which the fly-wheel action of the bulk of the mass is exerted.

But the spur-gearing is subjected to shock by the vertical oscillation of the motor and its casing carrying the bearings for the gear-shafts. This disturbs the uniformity of the relative speeds of rotation of armature and wheel-axle. If the wheel-axle revolve at constant speed, then the armature would also revolve at constant speed if there were no oscillation, or if, indeed, the motor with its casing rotated at any constant angular velocity round the wheel-axle upon which it is hung. If γ be the gear-ratio between pinion and spur-wheel, and if the motor casing rotated round the axle at any speed, this would cause an *extra* rotation of the armature and pinion greater than the casing rotation in the ratio $(1 + \gamma)$. Similarly, if there be any acceleration of angular velocity of the casing round the axle, it will cause an angular acceleration in the armature greater than itself in this ratio $(1 + \gamma)$; and this will cause hammering between the pinion and spur-wheel, or, at least, more or less severe variation of bearing pressure between the teeth. This is the effect which arises from the back of the casing being spring-hung, and from the

oscillations arising through this suspension. Let D be the quiet deflection of the suspension springs under the load of the motor, inclusive of armature, field, and casing.

Then, as above, the time of one complete oscillation is—

$$\text{T seconds} = 0{\cdot}32\sqrt{\text{D inches}}$$

and if d be the maximum deviation in either direction from the quiet deflection D, then the acceleration of linear velocity when this deviation is reached is $g\frac{d}{\text{D}}$. Then if L be the radius from the wheel-axle to the suspension springs and ρ the radius of gyration of the armature mass along with its shaft and pinion, the acceleration of linear velocity at the end of ρ will be $g\frac{d\rho}{\text{DL}}(1+\gamma)$. If, now, w be the weight of the armature, shaft, and pinion dynamically reduced to radius ρ, and r be the pitch radius of the pinion, the extra pressure between the pinion and spur-wheel teeth due to this oscillation will be the above multiplied by $\frac{w\rho}{gr}$, or

$$\text{Oscillatory Pressure between Gear Teeth} = (1+\gamma)\,w\frac{d\rho^2}{\text{DL}r}.$$

This extra pressure will be exerted alternately forwards and backwards, or as an addition to, and then as a subtraction from, the pressure of the steady driving torque. The alternations will occur with a frequency given by the above value of T.

The D to be used in these calculations is the steady deflection arising with zero driving torque.

If these oscillatory accelerations lasted long enough to produce any substantial change in the rotary velocity of the armature, they would produce pulsations in the counter E.M.F. of the armature, and thus pulsations in the electro-dynamic driving torque. It is not probable that any important effect of this sort is ever actually produced.

15. The mode in which the driving takes place must be clearly understood by those who wish to have thorough knowledge of tramcar motor action.

Assuming the motor to be in front of the wheel-axle driven by it, if this axle were held fixed, the armature pinion would climb up the spur-wheel if it exerted force enough between the teeth to lift the weight of the motor, and in so climbing would carry the motor casing with it. Now, when no driving torque is being exerted this weight is borne by the suspension springs with the deflection D. Therefore, as soon as any torque is exerted the motor casing is lifted and the springs relieved of part of the load. Let W be the weight

of the motor, including armature, field, and casing, statically reduced to the leverage L between axle and springs; and let R be the radius of the spur-wheel. The radius of the pinion being r, when a driving torque Fr is exerted, the springs will be relieved of load to the extent $F\frac{R}{L}$, and their deflection will be reduced from D to $D\frac{W - F\,R/L}{W}$. That is, the points of spring suspension of the casing will lift by the amount $D\frac{FR}{WL}$, or, introducing the factor r in order to express the lift in terms of the driving torque, this lift is $D.\frac{Fr}{WL}.\gamma$.

If the motor be slung behind, instead of in front of, the axle it drives, then the pinion must push the spur-wheel teeth *upwards*, and the point of spring suspension of the casing will be *depressed* by the amount $D\frac{Fr}{WL}\gamma$, making the driving deflection of the springs $D\left(1+\frac{Fr}{LW}\gamma\right)$.

The front position of the motor has the advantage that the working effort relieves these springs, while the hinder position strains the springs to an extra deflection proportionate to the driving effort.

It will be understood from what has been previously said that sudden temporary variations in the road and wind resistance have no effect in oscillating this spring suspension of the motor. The oscillations arise from the vertical pitching of the wheel-axle and of the truck-frame due to surface irregularities in the rails.

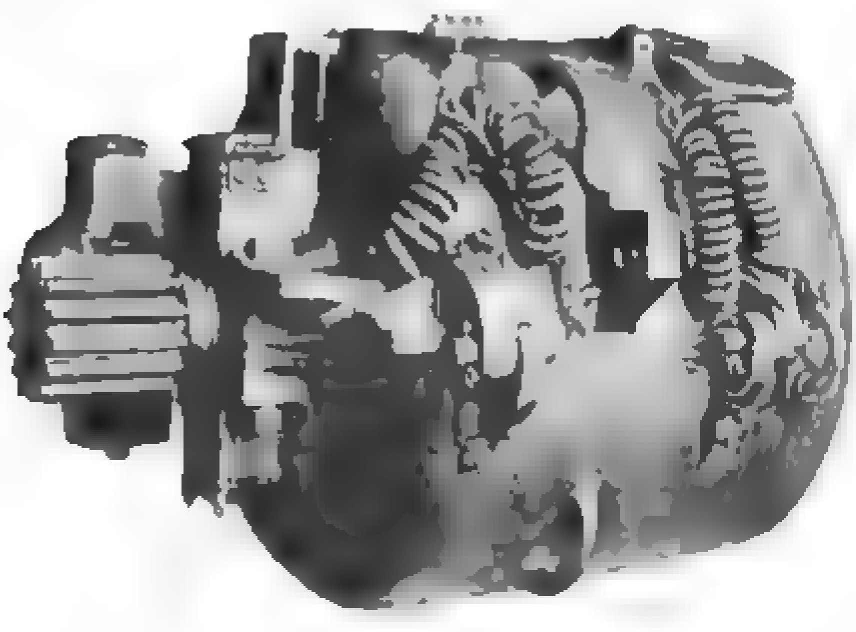


FIG. 39.—Glasgow Westinghouse Tram-Motor.

16. It is outside the scope of this treatise to detail the design of car-motors. These are fully described in books on electrical machinery.

Figs. 37, 38, and 39 show sufficiently well their general construction. Fig. 39 shows the appearance of the Westinghouse motor used at Glasgow. It is a four-pole machine with a two-circuit armature

winding, and is specified to exert a driving effort at the rails of 1600 lbs. at the speed of $7\frac{1}{2}$ miles per hour, which is equivalent to 32 horse-power, 375 mile-lbs. per hour being 1 horse-power. The gear-ratio is 4 to 1. There are two such motors on each car. Four-pole motors are now almost exclusively used on direct-current tramways.

Two of the poles are clearly seen in Fig. 38. The pole-pieces are laminated, that is, built up of thin soft iron sheets stamped to shape, the plane of each sheet being normal to the armature axis. Fig. 40 shows a pole-piece and its field-coil separate, with the bolts used to fasten it to the casing. Each pole-piece is divided in three parts to form ventilating ducts between them. The casing forms the common magnetic yoke for both pairs of poles. The field-coil is wound upon a former. The windings are connected so as to make north and

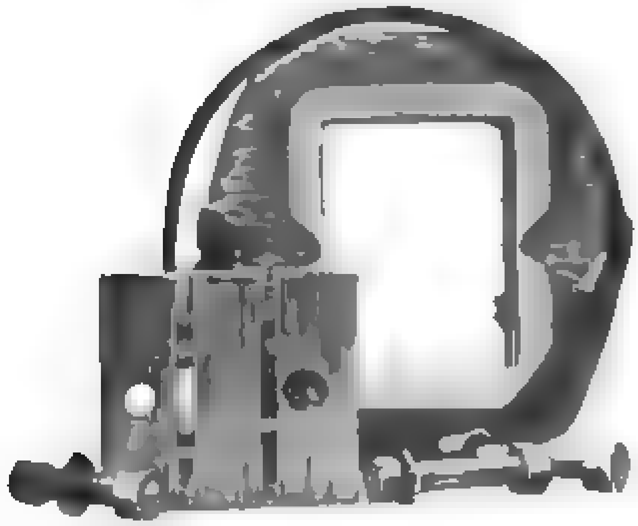


Fig. 40.—Field Pole-piece and Coil.

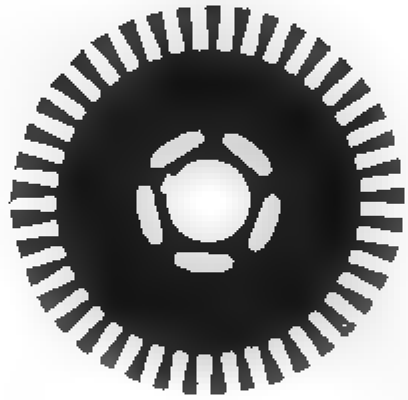


Fig. 41.—Core Disc of Armature.

south poles alternate. They are insulated with asbestos paper and cotton wrapping, and dipped in insulating composition after removal from the former. After drying, the coil is covered with mica, paper, and cloth, and taped with webbed braid, and is finally waterproofed. A metal frame is pushed into its centre to keep it well in shape, and to afford reliable means of securing it in place. The horns of the pole-pieces perform this last function.

The armature, which may weigh from 400 lbs. for a 20 horse-power to over 500 lbs. for a 30 horse-power motor, has its core built up of thin toothed discs stamped out of soft iron of special magnetic permeability and giving low loss by hysteresis. Such a disc is shown in Fig. 41. The round hole in the centre is of the same size as the shaft upon which the core is built. Fig. 41 shows the key-way slotted in the side of this hole. The five oval holes outside the centre are for air ventilating currents. In Fig. 42, which shows the

armature with its winding half finished, may be seen the open ventilating spaces left between the three sections into which the length of the core is divided. It is an advantage in the commutation to have an uneven number of slots and teeth in the core. The coils of the winding are prepared on formers before being laid in place. Thorough high-temperature drying of each coil after it is wound and wrapped, and before it is covered with the final insulation and taped, is of special importance. Particular care is also needed in the soldering of the open ends of the coils to the commutator bars. When the winding of the armature is completed, the coils are bound fast in the slots by tinned steel-wire bands. Carbon brushes in bronze brush-holders are now universally used in tram-motors. The brush-holders are mounted on the inside of the casing, the connecting cables passing through insulating bushes in this casing.

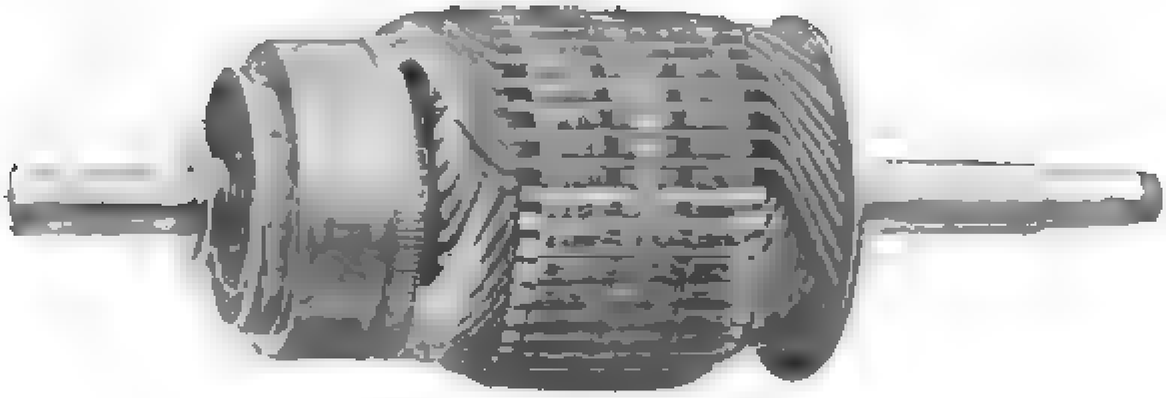


FIG. 42.—Motor-Armature partly wound.

17. Continuous current tram-motors are nearly always electrically connected up as series machines, that is, the main working current passes through the field-coils on its way to the armature. Figs. 43 and 44 illustrate the results obtained from such machines, the first being for a 24 horse-power, and the other for a 42 horse-power motor. The diagram for a 30 horse-power motor is intermediate between these, but rather nearer Fig. 44 than Fig. 43. All such diagrams are obtained from tests in which the voltage at the terminals (beyond the field) is kept constant. The diagrams here given are for 500 volts and 30-inch wheels. The "tractive effort" is obtained by multiplying the armature torque by the gear-ratio and dividing by the radius (15 inches) of the wheels. It will be noted that this tractive effort, as also the horse-power, decreases rapidly as the speed increases. The base ordinate always adopted for such diagrams is the current; but the curves become still more instructive, at least more readily intelligible in their practically important aspects, if converted to a base ordinate representing the speed. Another condition, not usually stated, is that the tests described by the diagrams are obtained

without extra resistance beyond those of armature and field inserted in the path of the current.

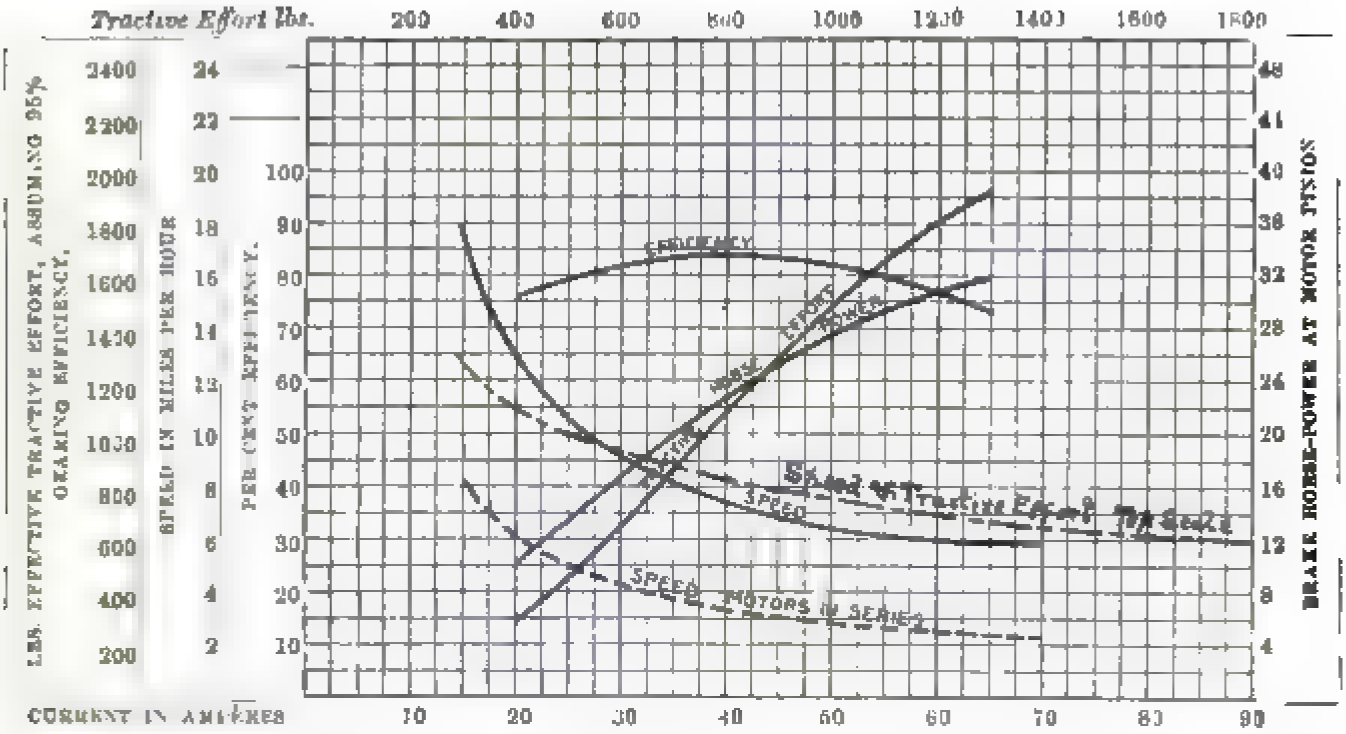


Fig. 43.—Traction Motor. Characteristic Curve.

Rated at 24 horse-power; Volts, 500; Gear ratio, 4·78; Wheel diameter, 30 inches.

The torque exerted, which is in constant proportion to the tractive effort, is proportional jointly to the strength of the field and to the

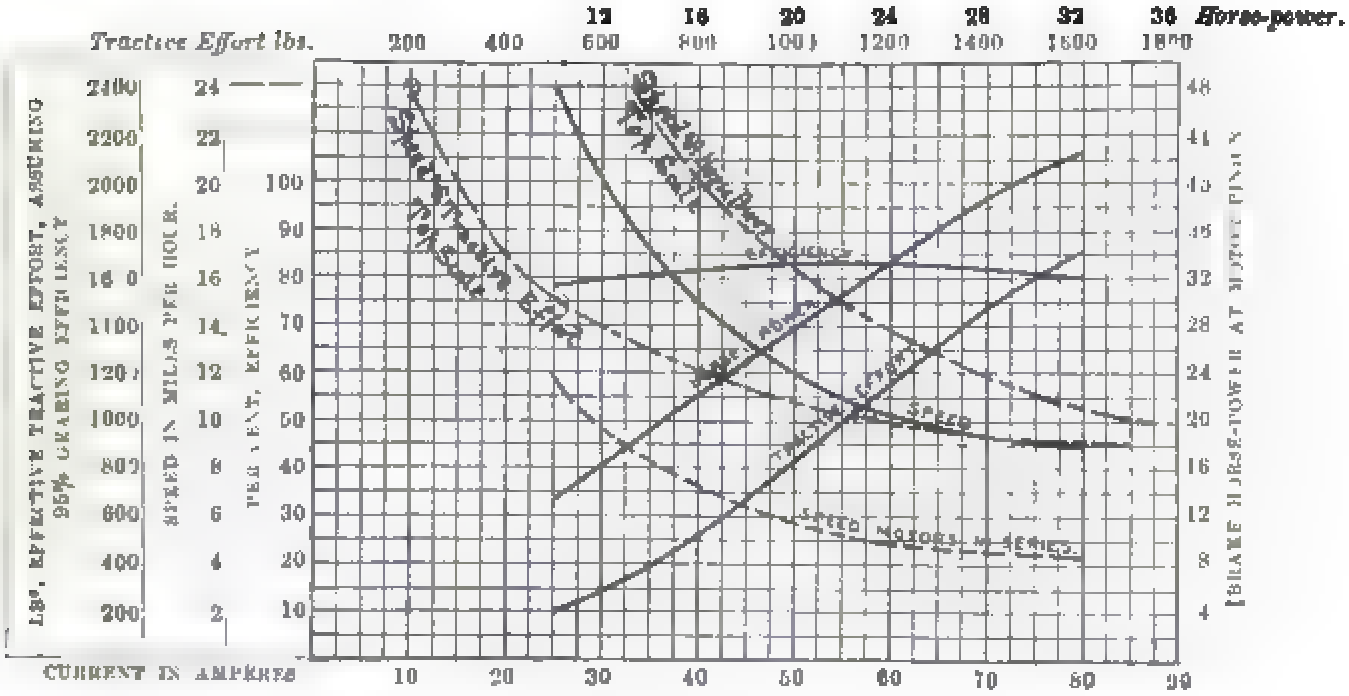


Fig. 44.—Traction Motor. Characteristic Curve.

Rated at 42 horse-power; Volts, 500; Gear ratio, 4·78; Wheel diameter, 30 inches.

armature current. The field strength increases with this current, but not in direct proportion to it; consequently the torque does not

increase so rapidly as the square of the current. Thus in Fig. 43, from 30 to 60 ampères, the torque increases less than threefold; and in Fig. 44, from 40 to 80 ampères, it increases in the ratio 3·4.

The field increases with the current in a manner dependent on the magnetic behaviour of the iron in the magnetic circuit and upon the law by which the magnetic leakage varies as the magnetic induction increases. This latter depends much upon the geometrical design of the motor.

The habit of electrical engineers of constructing these diagrams to an ampère base, which results from the method of testing, and also of habitually talking as if the current determined the speed, must often be misleading. As the curves show, there is for a given voltage a mathematical relation between current and speed, and in the purely mathematical aspect it may be said that current determines speed; but this is an inversion of the order of real physical causation. It is, of course, the speed that determines the current, and the speed in its turn is determined by mechanical conditions having no direct dependence upon the electrical action. The counter E.M.F. of the motor is conjointly proportional to the speed and the field-strength. As the speed increases, the excess of terminal voltage over counter E.M.F. decreases, and this excess drives a smaller current through the constant ohmic resistance of field-coils plus armature. Thus, as the speed is raised, both factors of the torque, current and field, fall off, and the torque decreases in a double ratio.

In order to exhibit this very clearly, a curve drawn in — — — line has been added to Figs. 43 and 44, giving the direct co-ordination of speed and torque, the speed taken to the vertical scale and the torque to a special scale along the top of the diagram. (This one curve only can be read to this top scale.) These curves show how very rapidly the torque falls off as the speed increases.

At any point of this curve the rectangle under the two ordinates, speed and tractive effort, is 375 times the horse-power. If the curve were hyperbolic the horse-power would remain constant at different speeds and currents. But as with rising speed the tractive effort falls off much more rapidly than the speed rises, the horse-power decreases with increase of speed. To show this, the curve co-ordinating directly speed with horse-power, the latter to the scale along the top edge of the diagram, has been plotted off in — — — line in Fig. 44. It is omitted in Fig. 43, because it falls too close to the speed and tractive effort curve.

18. At starting, *i.e.* at zero speed, there is no counter E.M.F., and the current, and consequently the field-strength, are determined solely by the terminal voltage and the ohmic resistance. But the ohmic resistance of field plus armature has to be made small in order to secure fair efficiency at normal horse-power; and the current that

would be passed by it alone would be so great as to damage the insulation. Extra starting resistance has, therefore, to be inserted; and this is cut out gradually as the speed rises.

At low speed the large torque is in excess of the road, wind, and frictional resistances; and this excess is spent upon the inertia of the car-mass, that is, in accelerating its speed. The excess continues in diminishing magnitude, and the speed always accelerates, until the torque has been decreased to equality with the road, wind, and frictional resistance. After this the speed is maintained steadily, unless new electrical conditions be introduced. Appropriate changes of these conditions are actually introduced by means of the "controller."

19. Before referring to the functions of the controller, it is well to notice that in tramway working the voltage at the motor terminals does not remain constant, as in the tests giving the above curves. The larger the current drawn off the line by each car, the greater is the drop of voltage along the line from the generating station, and the variation of current also reacts upon the central station dynamos, varying the E.M.F. they generate. Whether increase of current decreases or increases the dynamo voltage depends upon how these are wound. They are now usually "over-compounded" so as to raise the generated voltage, and thus to compensate in some degree for the greater loss along the line. If the power were always drawn off at one point only of the line, it would be possible to design the over-compounding so as to make the compensation always complete and exact, or nearly so; but this is actually impossible, because the power is taken off at each instant at many different places, and these places are continually changing.

20. When the motor terminal voltage is lowered, in order to get the same current as before the lowering, and therefore the same field-strength, the counter E.M.F. must also be lowered by the same amount —that is, in *more* than the same proportion—and this, because of the unchanged field, corresponds to an equivalent lowering of the speed. Thus, if the terminal voltage be halved, the speed giving the same current and the same torque as before becomes less than half. In Figs. 43 and 44 extra dotted speed curves are inserted for "two motors in series," which means practically halving the terminal voltage of each. At the same current and torque, the horse-power is, of course, reduced in the same ratio as the speed, that is, in a greater proportion than the terminal voltage; so that the electro-dynamic efficiency is lessened, independently of change in hysteresis and Foucault current losses.

As already stated, the armature current is injuriously great for very low speeds if extra resistance be not inserted. Setting two motors in series means the insertion in the circuit of each an extra resistance equal to that of field and armature combined, while this method of getting the necessary resistance avoids unnecessary waste

upon this resistance, the energy spent on it being usefully employed in the other motor. This consideration leads to the method of "series-parallel" control, the two motors on the car being linked in series at starting, and switched into parallel running after a certain speed has been reached. But in Figs. 43 and 44 the dotted speed curves corresponding to this series linkage do not run below 2 and 4 miles per hour respectively within the limits of the diagram, which limits correspond approximately to those of safe current through the armature. In actual starting, and up to these limits of low speed, therefore, extra rheostatic resistances are required. Fig. 45 shows one form of rheostat made for tram-cars by the Brush Co. It contains a series of from three to six resistances; more than four being rarely used for tramway work.

21. The "controller" is the complex switch whereby the driver inserts or cuts out extra rheostat resistance and alters the connection of the motors from series to parallel. By turning the handle of a barrel switch, which is the essential part of the controller, he successively (1) places the motors in series with full rheostat resistance inserted in front of them; (2) gradually (step by step) diminishes this resistance to zero; (3) weakens the field by shunting it; (4) cuts one motor out and inserts once more rheostat resistance, the one motor now having the full voltage except for this extra resistance, and having its field again in series; (5) inserts the second motor in parallel with the first; and (6) reduces the rheostat resistance step by step to zero, as full speed is approached.

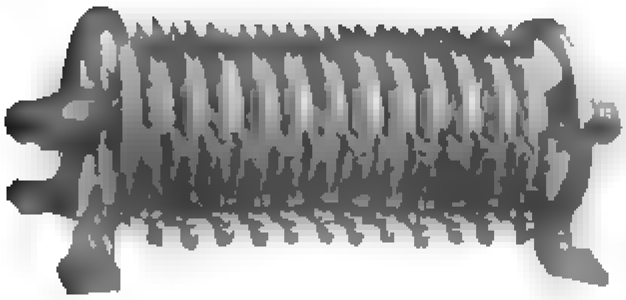


Fig. 45.—Tram-Car Rheostat.

Fig. 46 shows a controller such as is used by Dick, Kerr & Co., with the front cover removed. There are two rotative spindles carrying contact segments. These spindles are shown apart on the right-hand of the view. The short one, placed in the upper right-hand part of the casing, operates the reversal of the current through the field-coils, and therefore of the direction of the drive. It is interlocked with the other spindle in such manner as to prevent its being used for reversal except when the motors are cut out entirely; so that the reversal does not take place under current. The other spindle performs the function of regulating power and speed in the manner described above. The spring contact fingers are fixed to the inside wall of the casing. A soft iron magnet, electro excited, and with a number of flanges acting as poles equal to the number of contact segments, provides a magnetic field which blows out the arcs, or

sparks which arise when each contact is broken. The left-hand view in Fig. 46 shows this magnet slung out of place upon a hinge; while the right-hand view shows it in correct working position.

22. When a car is travelling at uniform speed, that is, with driving torque and resistance in exact balance and therefore without acceleration, if extra resistance be suddenly inserted, there follows

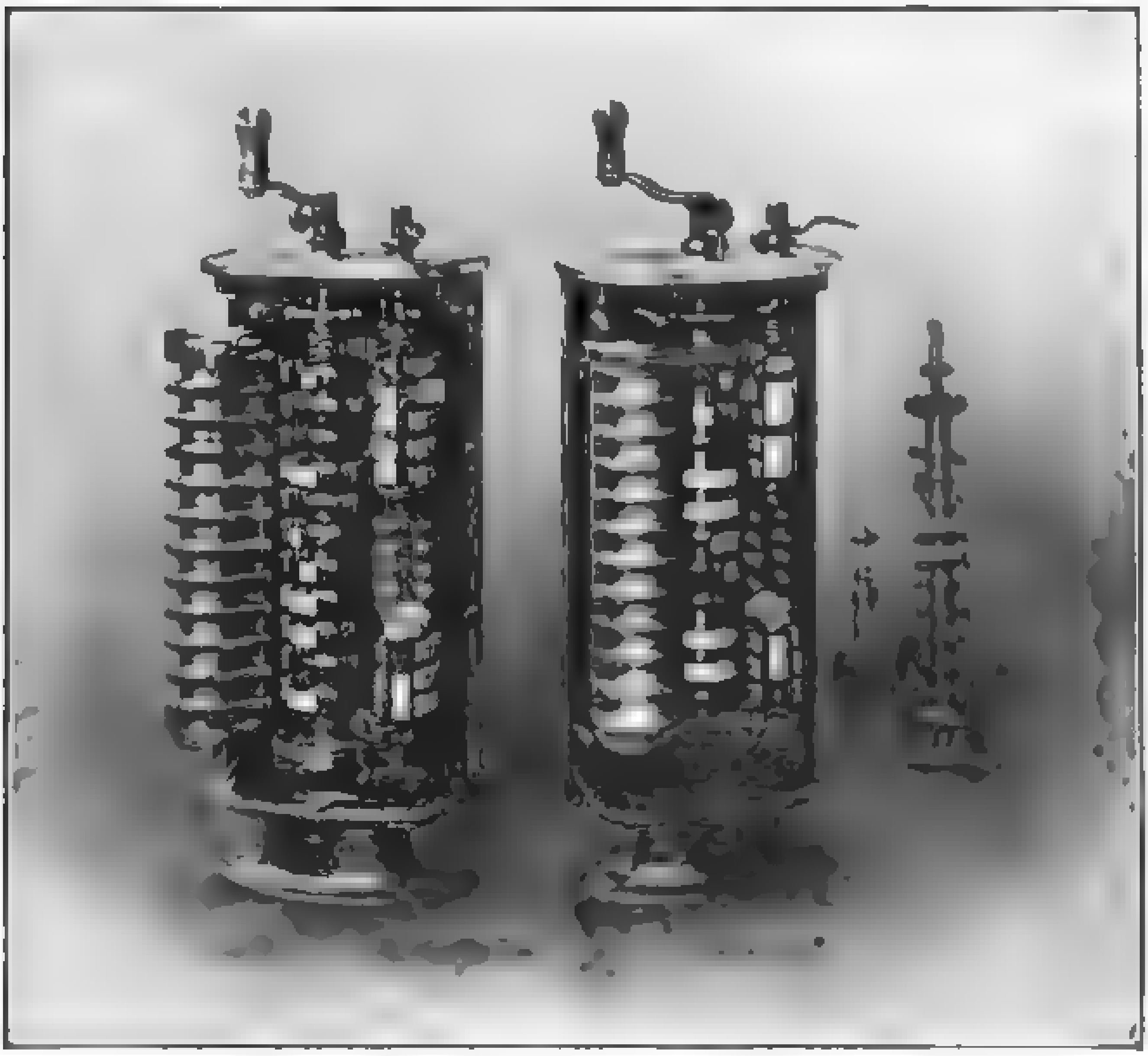


Fig. 46.

instantaneously a reduction of current through the motors, and therefore a weakening of the field and also of the torque in a double ratio. The driving force is now less than the resistance, and retardation of travelling speed immediately arises. Before this retardation takes effect, however, in reduced velocity—retardation is not a reduction of velocity, but a time-rate of such reduction and does not

result in reduction of velocity except with lapse of time—the motor counter E.M.F. is reduced because of the weakening of the field. This lessening of counter E.M.F. lets more current through, that is, partially neutralizes the decrease of current due to increase of ohmic resistance. Thus the reduction of current, and all the effects following upon it, are not in full proportion to the increased resistance inserted. Retardation, however, is started; and as the speed diminishes with lapse of time, the counter E.M.F., which is proportional to the speed, is further reduced. This leads to restrengthening of the current and of the driving torque, and this process continues until this torque is once more equal to the resistance, and steady speed is once more established. Equilibrium is re-established at a lower speed than before.

Exactly the reverse effects follow the cutting out of rheostatic resistance when the speed is steady. Equilibrium is re-established at higher speed.

Consider now the effects of the sudden occurrence of acceleration or retardation of speed at a time following perfect balance between driving torque and resistance, and this occurring without any alteration of the electric conditions such as insertion of resistance or change of voltage. Such acceleration is, of course, due to sudden reduction of wind, rolling, or other resistance, leaving an excess of driving over resisting force to be spent upon the inertia of the moving mass. This case is entirely different from those above considered in this one important respect, namely, that no *instantaneous* effects of any kind whatever result, except small ones in the distribution of mechanical stresses throughout the wheels and truck and car body. There is no instantaneous change in speed, or in torque, or current, or field strength in the motor. These changes do not begin until after the acceleration has had time to effect an actual integral change of speed in the car and in the motor, this change being slower the heavier the car and its passenger load are. As integral change of speed accrues, the counter E.M.F. of the motor increases; this decreases the current, and weakening of the field results. The weakening of the field reacts by way of reducing the counter E.M.F., so that this does not rise in full proportion to the increase of speed, nor does the current fall in the full proportion due to the actual rise of speed without field weakening. Both current and field are weakened, however, and the driving torque is lessened on both accounts. The rise of speed, the decrease of current, the weakening of the magnetic field, and the reduction of driving torque continue until this latter is reduced to equality with the new lesser rail and wind resistance. As soon as this equality is reached, a steady uniform travelling speed, higher than before, is once more established. The re-adjustment has been effected without the controller being moved.

A similar automatic readjustment at lower speed takes place when increased travelling resistance is offered to the progress of the car.

The travelling resistance is really always varying. It changes by change of gradient, of wind, of track curvature, and of smooth condition and cleanliness of the track. This automatic readjustment, with which the use of the controller has nothing to do, is continuously taking place.

The use of the controller is (1) to start and to accelerate up to full speed, and (2) to correct too great variations of speed arising from the above explained automatic balancing between resistance and driving torque.

23. Reverting to the above explanation of automatic rise of speed following decrease of resistance, this is accompanied by increase of counter E.M.F. in the motor. Suppose the process of fall of resistance and rise of speed and counter E.M.F. to be prolonged. Is it possible to bring the counter E.M.F. in this way up to equality with the terminal voltage derived from the overhead line? In a series-wound motor this is impossible, because as the excess of positive over counter E.M.F. decreases towards nothing, so also does the current, and therefore the strength of the field; while to this latter the counter E.M.F. is itself proportional. As excessively high speed needs only very small field strength for the generation of E.M.F., the limit towards which the motor E.M.F. rises is equality with the line-voltage; but no speed, however high, can make it reach this limit.

But if above a specified speed the field-coils be shunted—that is, if, instead of carrying the same current in series with the armature, they be connected across the motor terminals in parallel with the armature —then the current through the field-coils is due partly to the line-voltage and partly to the armature E.M.F., and these two act together, the currents due to them being in the same direction and being superadded. The field then becomes stronger as the motor E.M.F. rises, and thus there is no limit to the rise of E.M.F. as the speed rises. With this arrangement, provided the speed rises above a certain limit, the counter E.M.F. of the motor becomes greater than the opposite line-voltage; the motor is converted into a dynamo; it feeds current into the overhead line; instead of taking energy from the line, it supplies it to the line. This, of course, cannot occur except when the motor is being supplied with energy from some other source. This happens when the travelling "resistance" is negative, or becomes a positive propelling force exerted on the car. In going down long steep grades the propelling gravity force may be greater than the other resisting forces of wind and rail. Also during retardation the inertia of the car constitutes a driving force, the exhaustion of the kinetic energy of the mass being the source of supply of energy.

Thus the shunting of the fields at high speed is a useful means of utilizing energy that would otherwise be lost. This is done by the majority of recent controllers mounted on tram-cars. The process is conveniently termed electrical braking, since it always acts by way of lessening the speed that would otherwise be attained or maintained. But it must be remembered that the braking action can only be obtained above a certain critical speed, so that the car cannot be stopped or slowed down below the critical speed by this kind of electrical braking.

The reversing spindle of the controller has been already referred to. In starting, if the direction of the series current through the field-coils be reversed, this will reverse the polarity of the magnetic field. If the current through the armature were also reversed, then the two reversals would leave the direction of the torque unchanged. The controller reversing lever therefore reverses the current through the field only. The position of this lever therefore determines the direction of the torque, and therefore, also, that of the acceleration. In starting from rest the resulting motion will be in the direction of this torque and acceleration. But if, when the car is in motion in the direction of the torque, the reversing lever be thrown over, this will reverse the torque, and oppose it to the motion so as to brake the motion. Kinetic energy is given up, and the motor acts as a dynamo. In fact, as the E.M.F. depends solely upon the magnetic field and upon the motion, not upon the armature current, and as the motion is not reversed, while the field is so, the E.M.F. generated in this case is reversed, and is directed through the motor along with, instead of against, the line-voltage. This method of braking is admissible so long as the armature and field-coil current resulting from it is not too great.

If, on the other hand, the reversing lever of the controller reversed the current through the armature and not through the field-coils, then the desired reversal of the torque would be effected without changing the direction of the E.M.F. generated in the motor. With this arrangement there would be no risk of overloading the motor with excess current. But it would not suit for starting reverse motion from rest, because in this case, the motion being reversed without reversal of the field, the generated E.M.F. would be reversed, and the machine would work as a dynamo instead of as a motor; which, of course, is neither desired nor possible, since work has to be done both in overcoming the road resistance to backward motion and in creating kinetic energy, possibly also in driving uphill.

If the motor, while running, be simply short circuited inside the field—that is, with the field beyond the short circuit—this lowers to a small figure the potential difference across the armature due to the line-voltage, and the motor E.M.F. drives a reverse current through the armature and round the short circuit, thus working as a dynamo,

and braking the motion of the car. This action is commonly employed as an electric brake.

Controllers for railway work will be illustrated more fully in a subsequent chapter.

24. The brakes on the car are of paramount importance to its safe driving. Different methods of electric braking by direct action between the armature and the field magnets have been described above. In another indirect method of electric braking two soft iron discs are used, one fixed to the truck and the other keyed to the driving axle. These are kept apart by a spring except when the fixed one is magnetized by switching a current through a wire coil surrounding it, when they are pulled together and rub on each other. The action is stated to be not very reliable, and occasionally to result in clamping the discs fast together, and thus causing the wheels to skid upon the rails.

The hand brake is that most relied on for regular normal work. The wheel-block brake is almost universal. The blocks are linked together in such manner as ensures all being brought into equally close bearing upon the wheels by the pulling over of a single lever. Mr. W. G. Rhodes (see Vol. 31, Part 5, of the *Journal I.E.E.*) says that well-fitted hand brakes enable a careful driver to take cars down inclines of 1 in 10 safely.

When the routes involve steeper grades than this, skids or rail-block brakes are used, as in Rome where there are stretches of 1 in 8 down the Pincian Hill. The skids do not act on, or touch, the wheels; they act directly between the rails and the truck frame, lifting a part of the total load off the wheels and transferring it to the skid blocks. They may be pressed on the rails by a toggle-joint linkage, or by pneumatic pressure acting on a piston in a vertical cylinder, or by electro-magnetic force. Besides the vertical thrust, provision must be made for transmitting the horizontal drag of the rails on the blocks to the truck frame, and this is done by oblique tension-bars.

When there are no extremely steep inclines, these rail-skid brakes and the more powerful forms of electric brake are sometimes used as "emergency" brakes. These are essential, because of the necessity for very sudden stoppage in case of a living being falling across the track in front of the car, or in case of risk of collision with another vehicle; as also because of the possibility of a link in the ordinary brakework giving way at a critical moment or on an incline. An emergency brake must be designed so as not to interfere with the continued action of the ordinary brake, but to introduce an independent additional action.

25. The mode of action of wheel-block brakes should be clearly understood. There are both the linear motion of the whole car and

the rotary motion of the wheels to be stopped; but the energy of the latter bears a small proportion to the whole, and, for simplicity of explanation, its consideration may be here omitted. The blocks and their bearing-links exert force between the wheels and the truck to stop the rotary motion of the former. It must be assumed that all driving effort coming from the armature has ceased. The existing rotary momentum of the wheels and other rotating parts is small, and would be almost instantaneously extinguished by the brakes if these parts did not continue to be driven. How are they driven? It is the inertia of the car as a whole that exerts this driving force. It is exerted through the horn-plates and axle-boxes on the wheel axles. It results in continued rotation of these because the point of wheel-contact on the rail acts as a fulcrum round which the wheel turns and is driven in rotary motion. The driving force exerted by the horn-plates is forward; therefore the rails exert an equal (neglecting effects of rotary momentum) *backward* force. During ordinary driving by the armature the rails exert *forward* force on the wheels; it is this forward force exerted by the rails that balances the backward resistances offered to the progress of the car. It is essential to recognize that during braking the action of the rails is *opposite* to that exerted by them during driving. The backward rail-force is the only "external" force resulting in backward acceleration of momentum, that is, in retardation of forward momentum, of the whole car. This is not the working force that destroys, or absorbs, the kinetic energy; but it requires to be clearly understood that the retardation of momentum of the whole car is equal to the backward force exerted by the rails, and, therefore, cannot be greater than the load on the braked wheels multiplied by the coefficient of friction or "adhesion" between rail and wheel-tyre. If W be the weight of the whole car, and w that portion of it lying on the braked wheels, and f the coefficient of rail adhesion, the maximum possible retardative force is fw, and the maximum rate of retardation is $\frac{dV}{dt} = gf\frac{w}{W}$. Tram-rails being often in a very muddy, slippery condition, a larger value of f than $\frac{1}{10}$ cannot be relied on, making $\frac{dV}{dt}$ = say, $3\frac{w}{W}$ feet per second per second = about $2\frac{w}{W}$ miles per hour per second. If V be the speed in miles per hour that is to be stopped by pure brake action, then the least time in which this can be done is in seconds $T = \frac{VW}{2w}$, and the least distance is in feet $L = 0{\cdot}36\ V^2\frac{W}{w}$. For example, if $\frac{2}{3}$ of the whole load rested on braked wheels, the fastest retardation possible

would be 2 feet per second per second, or $1\frac{1}{3}$ mile per hour-second; the least time taken to stop from 10 miles per hour would be $7\frac{1}{2}$ seconds; and the least distance in which this could be done would be 54 feet. If the whole load be carried on braked wheels, the maximum retardation would be 2 miles per hour-second; the least time to stop from 10 miles per hour would be 5 seconds; and the least distance 36 feet. Now, in competitive brake trials these results are always surpassed, and stoppage from 10 miles per hour is effected in 18 feet or less, while such low results are attributed to the merit of the brake. The low results are only possible, however, because the trials take place on perfectly dry rails, on which the coefficient of adhesion may be as much as 0·3, or thrice as much as can be relied on in wet, muddy town streets. This coefficient would reduce the above 36 feet to a least possible minimum of 12 feet. One brake may be in many ways superior to another, particularly in respect of smoothness of action and in equal utilization of all the wheels to which brake-blocks are applied; but the best brake cannot overstep the limits of action imposed by the dry or slippery condition of the rails. Sanding wet and muddy rails improves their condition.

Reverting to our explanation of the action of the wheel-blocks, which is still incomplete, these apply to the wheels a backward turning moment, opposing the forward driving moment of the horn-plate pressure. The working force which destroys the kinetic energy is the frictional force exerted by the blocks, and the energy is spent in producing frictional heat. The frictional forces exerted by the wheel-tyres on the blocks deliver through these blocks to the truck and car as a whole a forward turning moment, which pitches these so as to lower the front end and raise the hinder end. The pitching of the truck compresses further the bearing-springs at the back, and relieves those at the front until the car body pitches through the same angle. This pitching is inevitable; it is intrinsic in the action of all patterns of wheel-brake. The moment producing it has a maximum possible amount equal to the rail adhesion multiplied by the radius of the running wheel; or $\frac{1}{4}fwd$, if d be the wheel diameter. It diminishes, so long as the braking continues, the load on the back wheels of the truck, and increases that on the front wheels by an amount $\frac{1}{2}fw\frac{d}{b}$, if b be the wheel-base. The angle of pitch depends upon the flexibility of the springs between axle-boxes and truck, not upon that of the springs between truck and car body. If the truck were rigidly borne by the axles, the angle of pitch would be reduced to zero. If the normal load on each of the two sets of springs, front and back, be $\frac{1}{2}w$, and the spring deflection under this load be D, then the change in this deflection due to maximum brake action is $D\frac{1}{2}fw\frac{d}{b} \div \frac{1}{2}w = fD\frac{d}{b}$, and the angular pitch of the

truck is $2fD\frac{d}{b^2}$. The pitch of the car body following that of the truck may have an angle greater than that of the truck by reason of suddenness of lurch setting up an oscillatory swing of the car body upon the springs between it and the truck. This pitching action of the brakes is a matter worthy of serious consideration by engineers. Because of it, the smooth working of the brakes is of extreme importance in respect of the comfort of the passengers.

26. It is very frequently said that it is important to limit the action of the wheel-blocks so as to avoid stopping the rotation of the wheels and thus making them skid upon the rails. This is true, because so doing avoids abrasive wear of the rails in braking and avoids wearing flats upon the tyre surfaces. If the wheels be skidded, their rotation is sure to stop when an already started flat is on the rails; so that a flat once started is certain to be aggravated. The cost of repairs in re-turning the tyres is thus greatly raised. But it is very often assumed that one gets a greater possible braking effect by this correct method than by skidding the wheels, the supposed reason being that the coefficient of friction between tyres and brake-block is greater than that between tyres and rail. This latter may be always, and certainly is usually, true; but the above explanation of the action shows that the block-tyre friction cannot be utilized beyond the limit of the tyre-rail friction, and must be used to a less limit than this in order to secure the desirable result of maintaining the wheels in rotation. The real advantage of so doing lies in not wearing flats on the tyres, and in throwing nearly all the wear upon the wood blocks, which are very cheaply and quickly renewed. One other advantage consists in the much greater uniformity and less jerky action of the pressure and friction between block and tyre than between tyre and rail.

27. The current is brought to the motors through the roof of the car from the overhead line by a rolling or sliding collector. Very many forms of collector have been used, but in modern work varieties of two forms only are employed, namely, the trolley-wheel and pole and the bow. The trolley alone is used in Britain and America. The bow has been most common on the European Continent, but it is now being replaced in many places by the trolley.

In a two-deck car the trolley-pole is mounted on a pillar, as seen in Figs. 25 and 26, so as to raise it above the heads of the passengers. In a single-deck car its base is upon the roof, as shown in Figs. 30 and 31. The base swivels upon a vertical bearing and swings on a horizontal hinge-bolt. A crank-arm at the base carries the crosshead to which are attached the coil-springs which elevate the pole. The arm and the springs should be set at such an angle that as the springs extend the leverage of their pull is diminished,

giving an approximation to constant moment and constant pressure of the trolley-wheel on the overhead line in spite of variations of level of this latter. Fig. 47 illustrates one pattern of wheel. It is important that it should be free to swivel on a vertical pin in order to keep in alignment with the overhead wire while the pole swings to different horizontal angles with this wire. Another important feature is the guard which prevents cross-wires being caught by the wheel if it jumps from the line when the car is running. Such entanglement inevitably breaks the wire and causes risk of very serious accident. The originator of the swivel and guarded trolley-wheel was Alfred Dickenson, of Birmingham. The mechanical

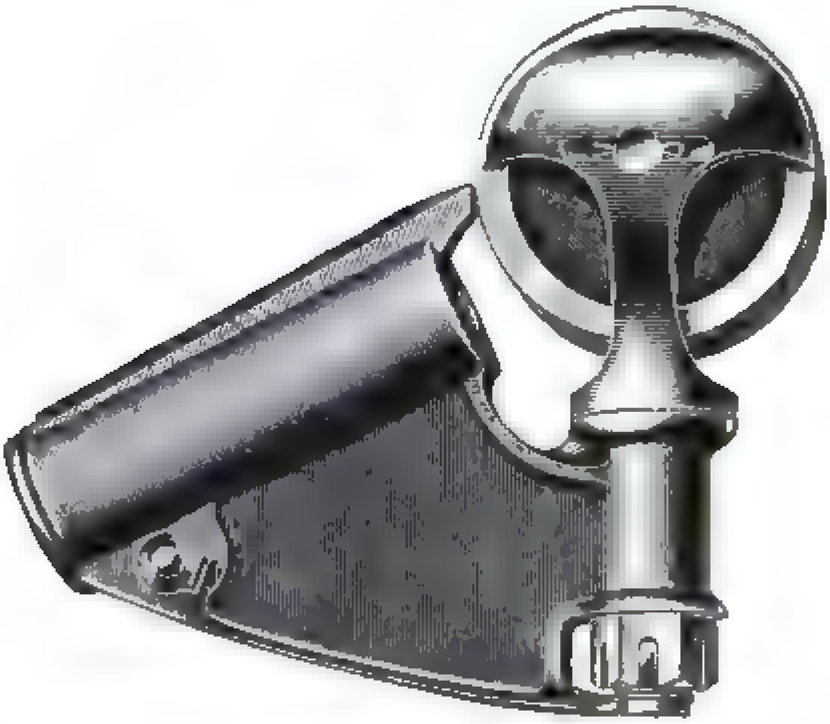


FIG. 47.

pressure needed between the wheel and the overhead line is regulated by screwing up the springs at the base. It is from 10 lbs. to 12 lbs., but differs considerably according to the design of the wheel and the smoothness of the track run over. The pressure is needed solely for the purpose of maintaining close electric contact. This is broken every time the wheel jumps, even a hundredth of an inch from the line-wire. Such jumping occurs chiefly at the points of support of the wire, and the design of these supports is therefore of great consequence. The pillar base and all parts accessible to the public must be kept at earth potential by being in good metallic contact with the running-wheels, and it is thus essential to bring the current down from the trolley-wheel by a well-covered insulated cable, which passes down the interior of the tube forming the pole;

and the trolley-wheel itself must be well insulated from this pole. This can best be done by an insulating joint between the outer end of the tube and its metal extension upon which the swivel mounting of the wheel is arranged.

28. Fig. 48 shows a bow collector (Fr. archet, Ger. Biege), a form introduced by Siemens and Halske. Here the contact is a sliding one. The contact piece may be a steel tube or steel bar covered with tin The most recent form, shown in Fig. 49, is a deep U section made in aluminium. The hollow of the U is filled with semi-solid or solid lubricant to diminish the friction of the rubbing contact. The tin-covered bar lasts for a fortnight only, but the aluminium U bar lasts three to four times as long. The abrasion of the overhead line-wire is severe, and becomes expensive in repairs. The main advantage of the trolley-wheel is that it removes nearly all the wear from the overhead line, which is of expensive copper and the renewal of which is troublesome and costly in work and time, to the bearings and journals of the trolley-wheel spindle and the surface of the wheel itself. These are repaired cheaply and in the repairing shop, so as not to interfere with the continuous use of the line and of the car, a worn wheel being replaced by a new one in very few minutes. The bow is also heavier than the trolley-pole and wheel. The bow has two advantages. It requires no swivelling joints. It also works well at curves with large angles between the successive spans of the wire, which spans may therefore be large, there being no need for the wire to follow closely the curve of the rails.

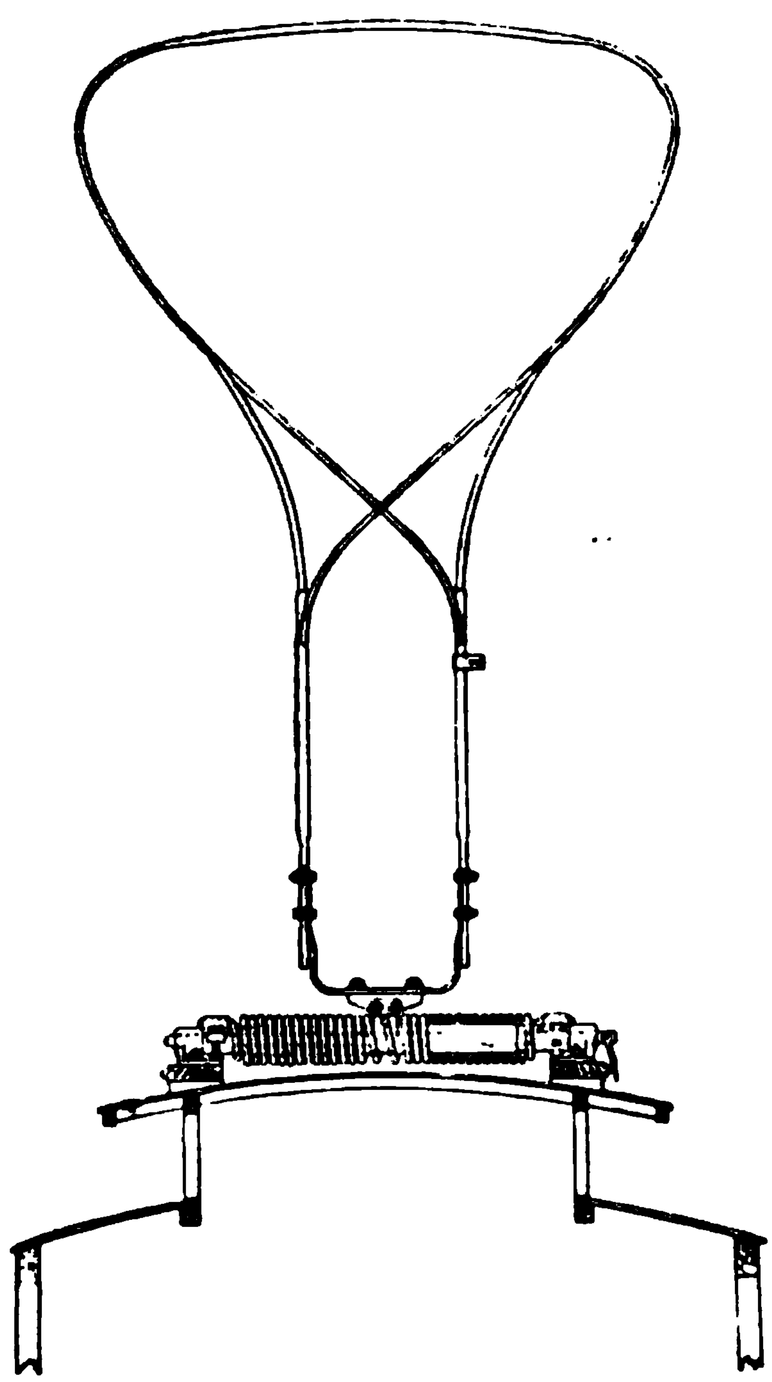


FIG. 48.—Siemens' Sliding Bow Collector.

29. A modification of the bow collector consists of a pole ending in a wide fork, which carries ball-bearings for a roller of cylindrical or fish-belly shape. The roller may be a steel tube or a wooden bar, in either case covered by a thin tube-sheath of hard, tough copper or bronze. An example of this construction

is shown in a later chapter on the Valtellina high-tension Ganz railway.

30. Other forms of section than the circular for the line-wire have been used, but on account of their twisting and thus not always presenting the right face downwards, they have been found incon-

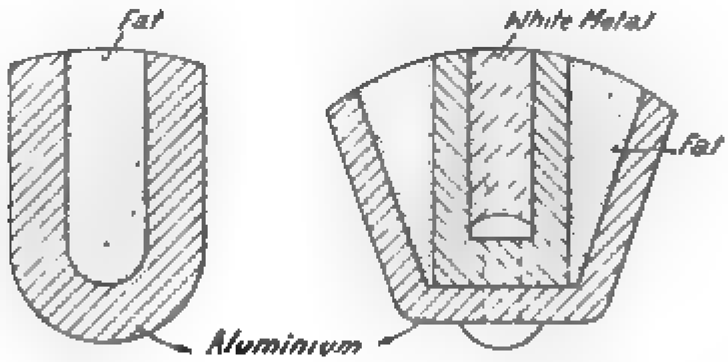


FIG. 49.—Two Sections used for Bow Collectors.

venient. A grooved or bull-head rail section gives great facility for the suspension clamps, but, on the above account, has not been a success. Round wire is thus almost universally used. It is of best conductivity copper, or sometimes of aluminium. The sizes in use are—

Wire Gauge, No.	0.	00.	000.	0000.
Diameter, inch	0·325	0·365	0·410	0·460
Area, square inch	0·083	0·1045	0·132	0·166
Weight, pounds per 100 yards ...	95	121	152	192
Electric resistance, ohms per mile	0·501	0·363	0·311	0·242
Electric resistance, ohms per 100 yards	0·029	0·021	0·018	0·014

These are American wire gauges, and do not correspond exactly with any of the numbers of the British standard wire gauge. The two largest sizes are rarely used.

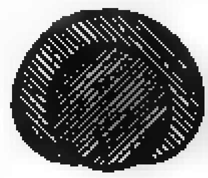


FIG. 50. — Section of Line-wire Ear.

31. The wire is suspended by what are called "ears." The ear embraces the wire in the manner shown in Fig. 50. Ears are made in two main forms, solid, as shown in the figure, and split vertically, with the two halves clamped tight together upon the wire by screws. The ear is of cast metal, generally tough brass or bronze. When solid it is necessary to

solder the wire into it, and for this reason the inside surface of the ear is tinned. Figs. 51, 52, 53, 54, 55 show five forms of ear. Fig. 52 is a very efficient simple form of plain ear for a straight run of trolley-wire. Fig. 53 is a form for securing two ends of two wires. Fig. 54 shows a form adapted to "straining," or pulling up taut, the wire already clamped in it. Fig. 55 illustrates the provision made for coupling a feeder, which brings the current into the line through one of the suspending ears.

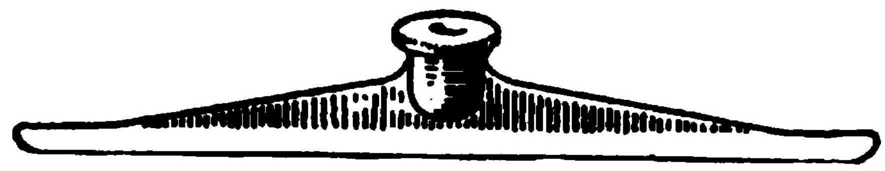


FIG. 51.—Plain Ear for Straight Line-wire.

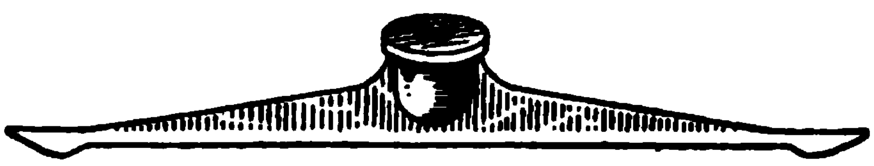


FIG. 52.—Lip Ear for Straight Line-wire.

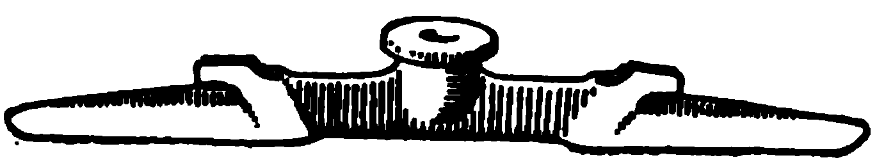


FIG. 53.—Splicing Ear.

Fig. 56 shows a special tube used for splicing a broken wire between two points of suspension. Each form of ear has a boss in the middle of its upper side, into which is screwed the suspending bolt. This bolt usually passes vertically

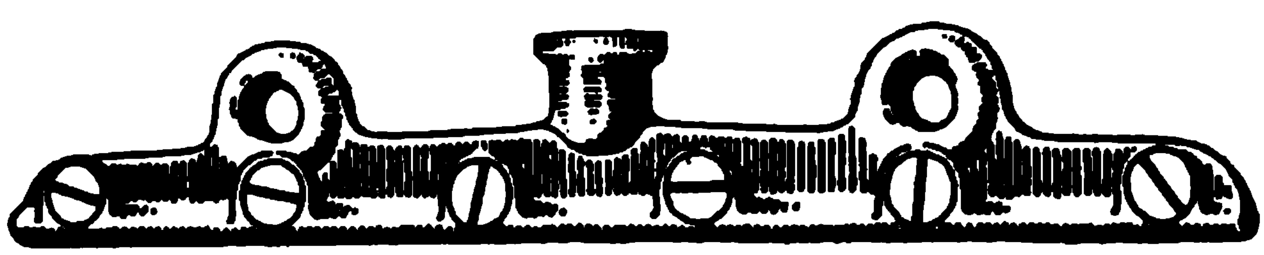


FIG. 54.—Strain Clamping Ear.

through the body of a bell-insulator, which is supported from its outside surface.

The bell of the insulator is of cast metal, usually of malleable cast-iron. It serves as an outside protective covering to the insulating material, which is moulded inside it and round the suspending bolt, and also as means whereby the supporting wire may lay hold of the insulator firmly without risk of breaking or cracking the insulating core. The rain is shed from the lower edge of the metal bell.

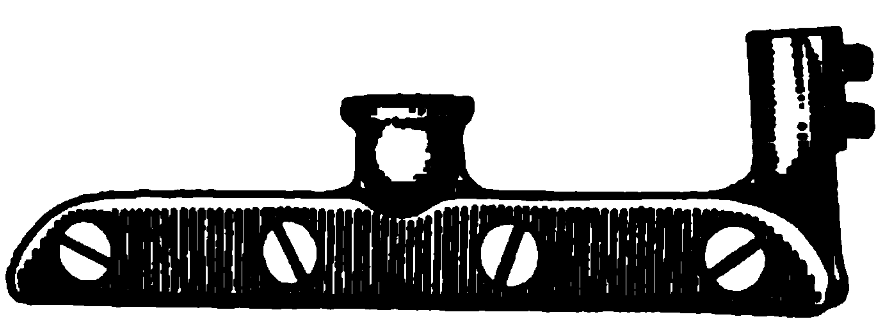


FIG. 55.—Feeder Clamping Ear.

FIG. 56.—Trolley-Wire Splicing Sleeve.

The insulator is sometimes mounted rigidly on the bracket of a pole, but elastic suspension by a wire is now almost universal. It may be hung direct on a steel "span-wire" stretched across the whole width

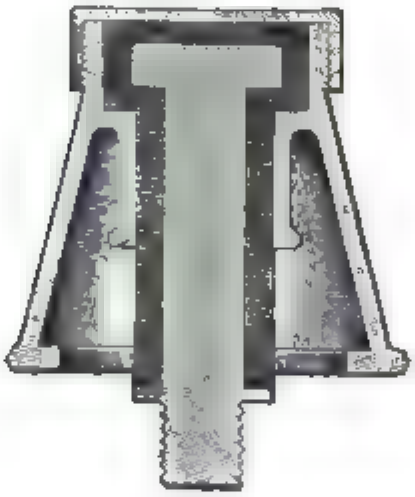


FIG. 57.

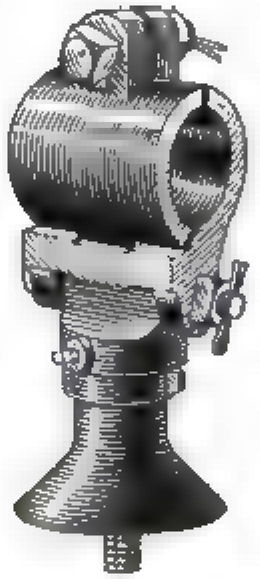


FIG. 58.—Bracket Suspension.

of the road, and secured either to the walls of houses by cast-iron anchor-plates, called "rosettes," or to poles erected on either side at the curbs of the footpaths or pavements. Or it may be hung upon pole-brackets extending right over the line-wires.

Fig. 57 shows the section of a bell-insulator. Fig. 58 shows how it may be suspended by a swing-joint direct on a pole-bracket.

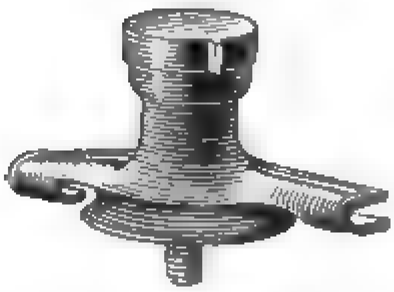


FIG. 59.—Straight Wire Suspension.

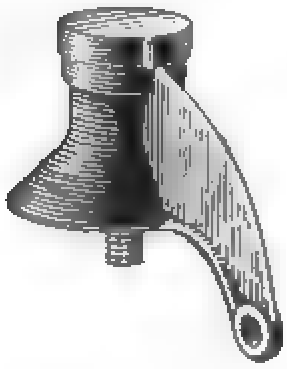


FIG. 60.—Strain Suspension.

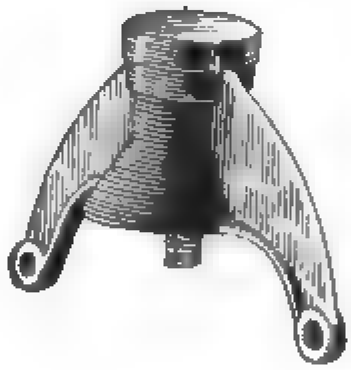


FIG. 61.—Double-Arm Strain Suspension.

Fig. 59 shows a form for suspension on a straight length of wire. When the insulator and line-wire have to be pulled horizontally and transversely in any direction, as at curves on the track, the suspensions shown in Figs. 60 and 61 are used.

32. In Glasgow the ears are 18 inches long. The span-wires are stranded ropes of seven galvanized steel wires. The rosettes have

thick rubber washers inserted in them, on which the pull of the span-wire is taken, and which damp out vibration coming from the line. Fig. 62 shows one of the Glasgow side-poles to which span-wires are attached when no buildings are available for the purpose. The post

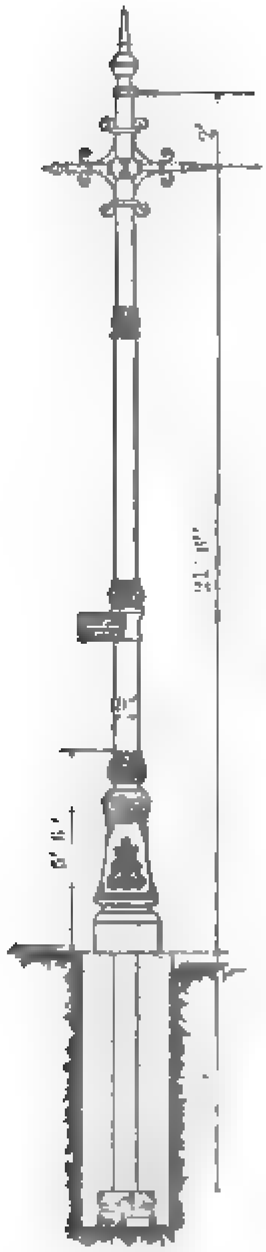


Fig. 62.—Glasgow Side-Pole for Span-Wires.

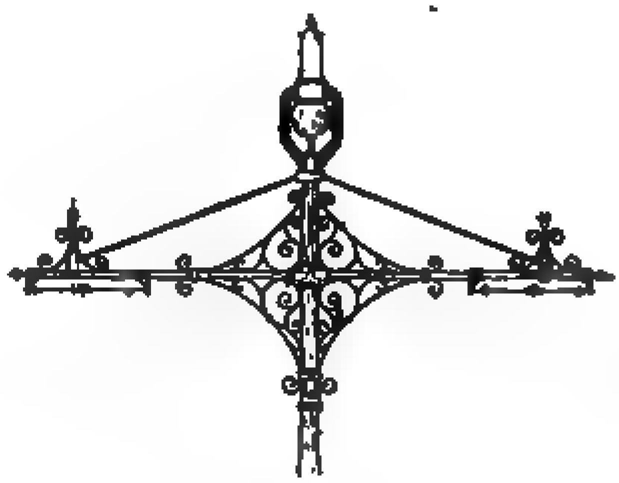


Fig. 63.—Glasgow Double-Track Centre-Pole, with Arc-Lamp.

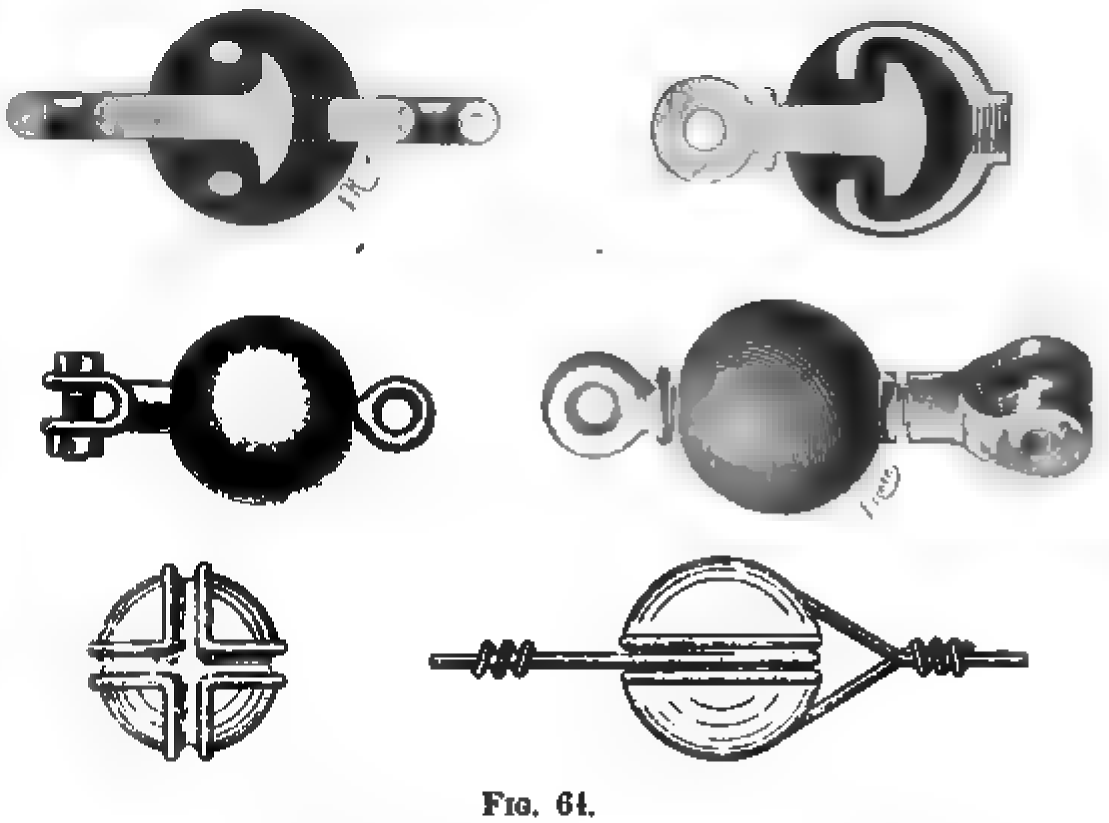


Fig. 64.

is made of steel tube in three lengths, screwed together. It is 9 inches in outside diameter at the base, and the attachment of the span-wire is 21½ feet above the pavement. A guard-wire is stretched 2 feet above the span-wire. Fig. 63 is a Glasgow centre-pole, double armed, with elastic suspension of the insulators carrying the line-ears. A

side-post for carrying the line directly without span-wires is practically the same as Fig. 63, except that it has one arm only.

In the elastic suspension the ear and insulator are mounted on a short length of wire stretched between two small brackets clamped to the arm of the post. In Fig. 63 this wire is insulated at each end from the bracket by what is called a "ball-insulator." This, as shown in the upper part of Fig. 64, consists essentially of two iron hooks engaging each other, not directly, but through a spherical mass of insulating material cast about them. The shank of one of the hooks is screwed, and a screw-sleeve gives means of tightening up the wire to the desired tension. The "Brooklyn" design takes cylindrical form, being practically a cylinder and a piston and piston-rod, the piston being smaller than the cylinder, and the space between the two being filled up with rigid insulation cast in. The simplest of all forms, called a "pulley," is made of porcelain, and is shown in the lower part of Fig. 64. A simple addition to the design shown makes it capable of screw-adjustment of the strain.

FIG. 65.—Trolley-wire Crossing.

In this elastic suspension there is twofold insulation if the centre-suspension be by a bell-insulator. Sometimes, but rarely, one of the two insulations is suppressed.

33. At points and crossings special guide-plates are required which permit the passage of the trolley wheel-flanges. These flanges, of course, reach higher than the trolley-wire, and, therefore, at a crossing the crossing wire must be cut away—that is, both wires must be cut away. Above them is fixed a flat plate upon which the flanges run. During the passage of a trolley-wheel the collecting contact for the current is between this plate and the flange edge. Neither flange passes through the centre of this plate, and, therefore, a pin or stud projecting downwards from this centre causes no obstruction to passage along either line. It is inserted in order to help in guiding the wheel to pass through the centre in the right direction. In Fig. 65 is seen in outline such a crossing. The wires

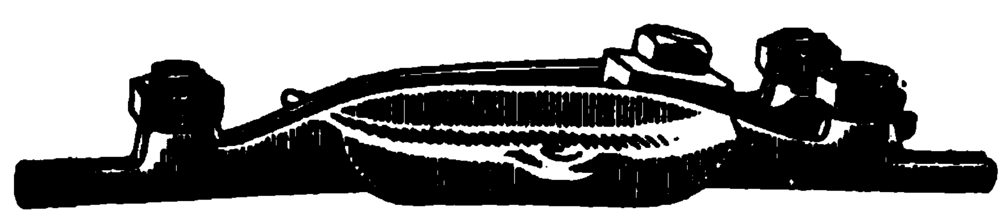


FIG. 66.—Trolley-wire V-Frog Point.

are held in place by pinch-screws; and they may either run through the crossing uncut, passing over the centre-plate, or they may be cut and the four ends secured by turning them over cross-pins let into the ribs of the crossing. These are usually cast, but they may also be stamped. Many different patterns are in use.

At points, where two wires meet or diverge, a similar plate is necessary. One pattern is shown in Fig. 66. These are generally termed "V frogs."

34. Figs. 67, 68, 69 show in section, sectional plan, and elevation, the standard rail used in Glasgow, and the method of copper-bonding the lengths together. It weighs 100 lbs. per yard, and is

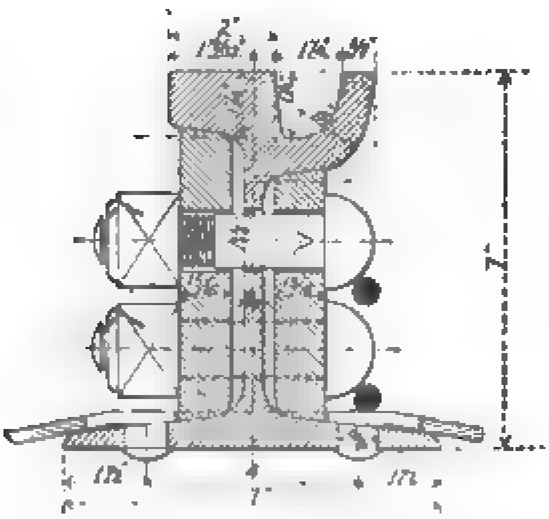


Fig. 67.

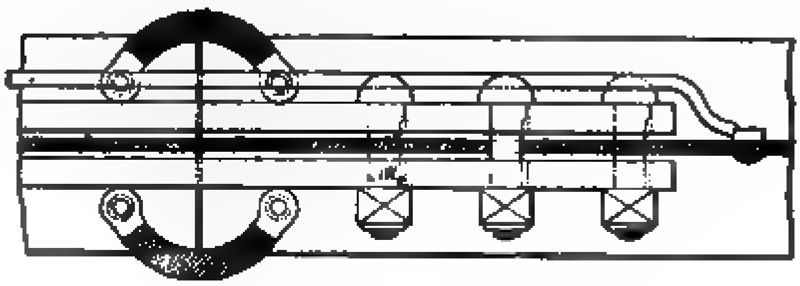


Fig. 68.—Method of Rail Bonding. Plan.

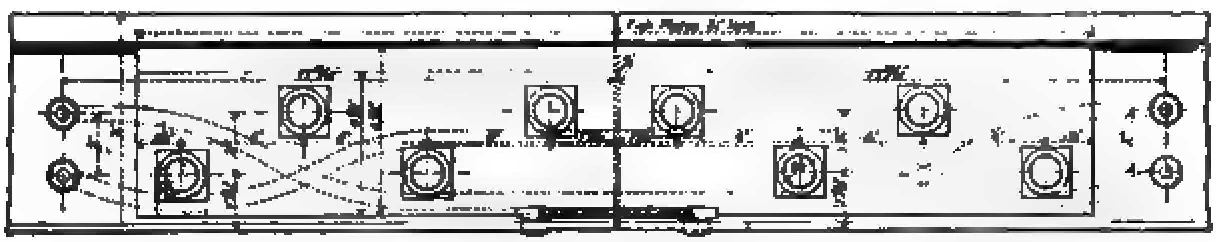


Fig. 69.—Elevation of Bonded Joint.

rolled in 60-feet lengths. Its height is 7 inches; sole-flange, 7 inches; width of groove, $1\frac{1}{4}$ inch; width of tread, 2 inches. Two side steel fish-plates are used at the joint, each $\frac{13}{16}$ inch thick and 31 inches long, secured to each rail-end by four 1-inch bolts. Four copper bonds are used at each joint. Two of these are short, and are of stranded copper wire, the terminals being fixed in the sole-flange. The other two are of solid wire. They are 3 feet long, with terminals in the rail-web beyond the fish-plates. All four rails of the two tracks are copper cross-bonded at spacings of 40 yards on level roads, and of 20 yards on gradients. The rails are tied together by 2-inch

by $\frac{3}{8}$-inch steel gauge-bars spaced 5 feet apart. In Fig. 67 the "lip" of the rail outside the groove is $\frac{3}{8}$ inch thick. At sharp curves a rail with 1-inch thick lip is used, with its other dimensions the same as on the straight parts of the road.

35. Figs. 70 and 71 show in section and plan the Glasgow roadway. Six inches depth of cement concrete is laid under the rails and the whole breadth of the double track, extending on each side 18 inches beyond the rails. The surface is paved with granite setts, grouted with pitch and granite chips. As seen in Fig. 71, at each side of each rail chilled cast-iron blocks are set alternately with the granite blocks. These are used only in streets where the vehicular traffic is heavy. They have a chequered surface 6 by 4 inches wide. These last well, and prevent the wear of the road surface into ruts

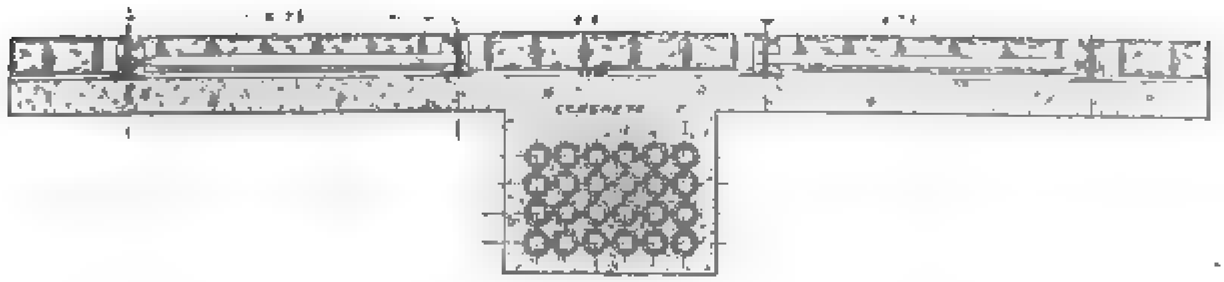


FIG. 70.—Section of Tramway, Glasgow.

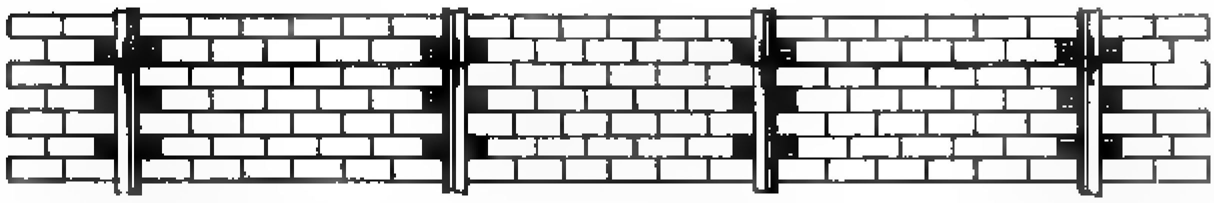


FIG. 71.—Plan of Tramway, Glasgow.

along the sides of the rails, this wear arising from carts and lorries. At suitable intervals drainage catch-pits, 4 feet wide by $3\frac{1}{2}$ feet deep, are provided, and these drain directly into the sewers.

36. Fig. 70 shows the feeder cables laid in the centre of the way in a mass of concrete. Fig. 72 shows the trench in which these are laid in process of construction. Figs. 73 and 74 show two of the manholes giving access to the cable junctions. These vary in size according to the number of cables. The ducts are in some cases Doulton fire-clay pipes, and in others of circular tube section made of iron lined with cement. In different places there are from one to six tiers, and each tier contains from three to twenty-seven ducts. Every duct is large enough to take a 3-inch cable. Three inches depth of concrete is laid between each tier, and also 3 inches below and above the lowest and highest tiers.

The direct-current 500-volt feeder cables are insulated $\frac{1}{8}$ inch thick with Manilla paper, and lead covered to $\frac{3}{16}$-inch thickness. They are tested under water to 2500 volts, and again to 2000 volts after being drawn into the ducts and jointed. Those most used have 0·4 and 0·6 square inch section; but some have as much as 1, and others as little as 0·1 square inch. There are between sixty and seventy of these feeder cables issuing from five sub-stations.

The three-core cables for the three-phase high-tension transmission to the sub-stations are of 0·10 and 0·15 square inch section. One-eighth inch thickness of insulation of oil-impregnated Manilla paper lies between each core. The three cores are stranded with a

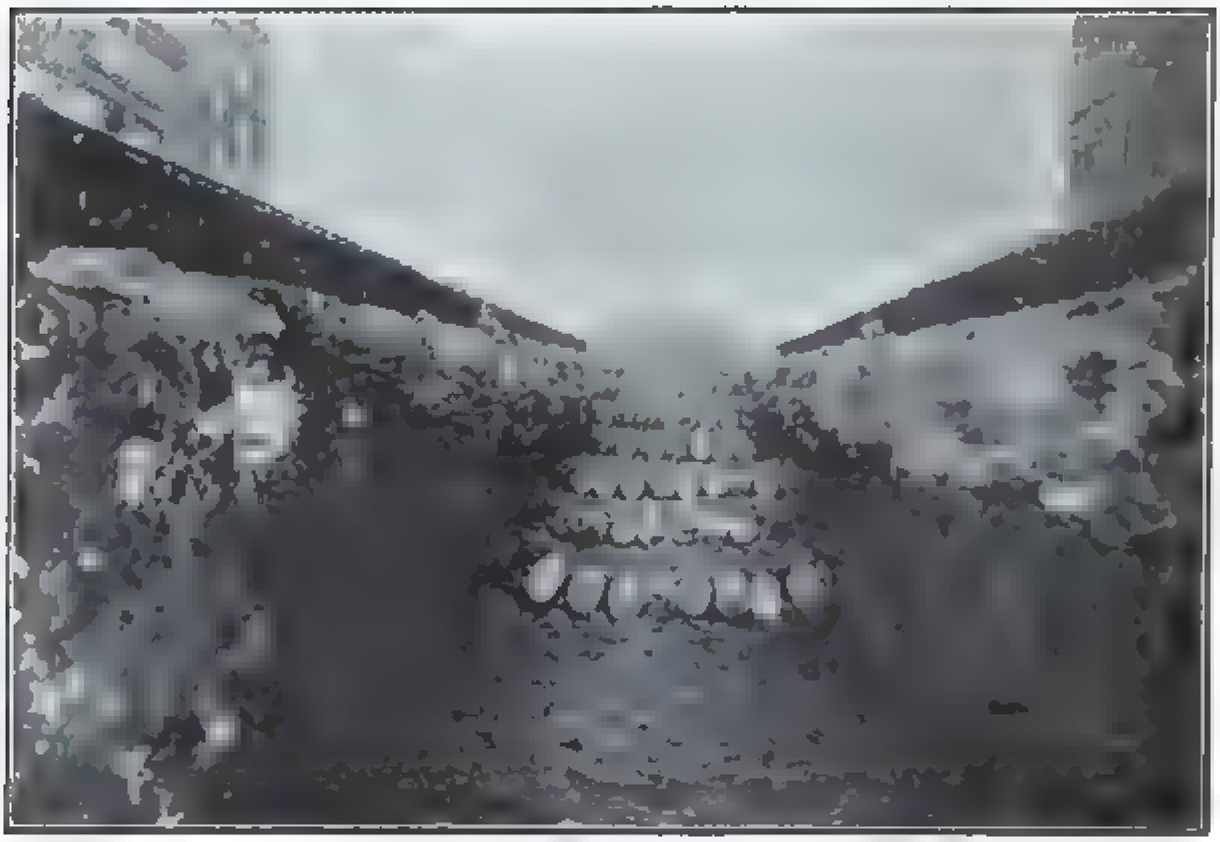


FIG. 72.—Feeder-Cable Ducts in process of laying.

long lay, and the whole covered with $\frac{1}{8}$-inch insulation, and then with $\frac{3}{16}$-inch lead sheathing. They are tested under water to 20,000 volts, and again to 15,000 volts after being drawn in and jointed. There are twenty such cables, four to each of five sub-stations.

From the main feeders to the trolley-wires the connection is by cable consisting of sixty-one strands of No. 18 S.W.G. wire. These leave the main feeder through a switch-pillar, and from this branch to various points along the route. Each passes through a subsidiary switch-pillar at the base of the pole, up the inside of which it is carried to the trolley line.

Besides these there are over a score of return feeders for negative boosting of the rail return, whereby it is endeavoured to keep down the drop of voltage along the rails to between three and four volts.

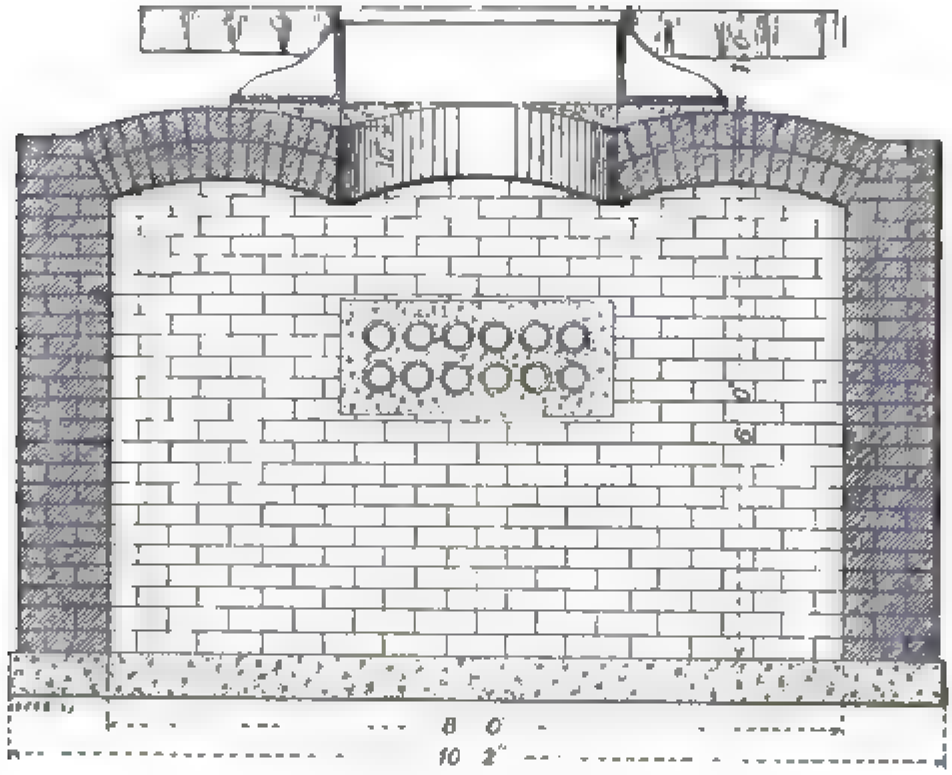


Fig. 73.—Large Manhole to Cable Junction.

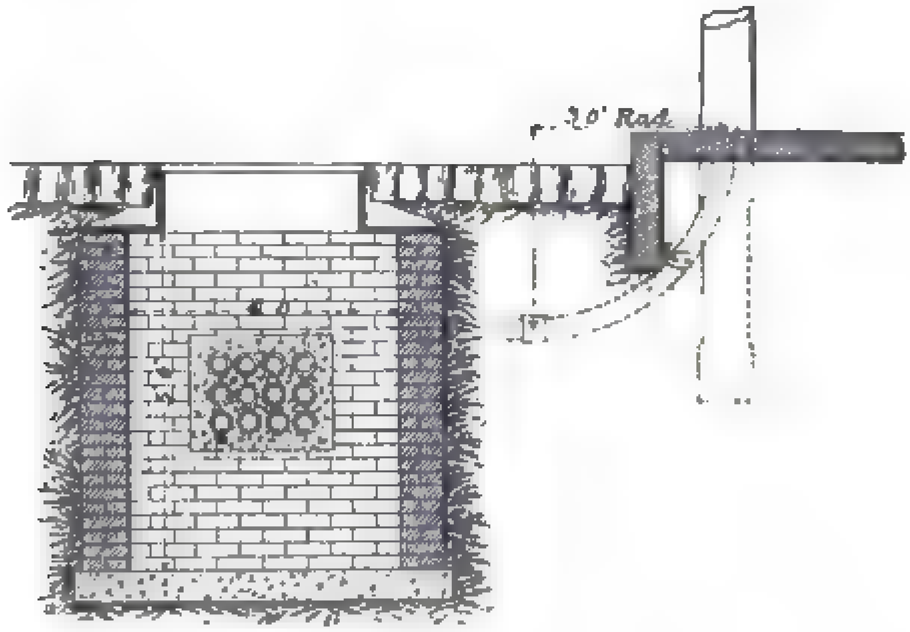


Fig. 74 —Small Manhole to Cable Junction.

These negative feeders are of two sizes only, 0·8 and 0·6 square inch section.

37. The map (Fig. 75) shows very distinctly the course of the five high-tension routes from the Pinkston Central Power Station to the

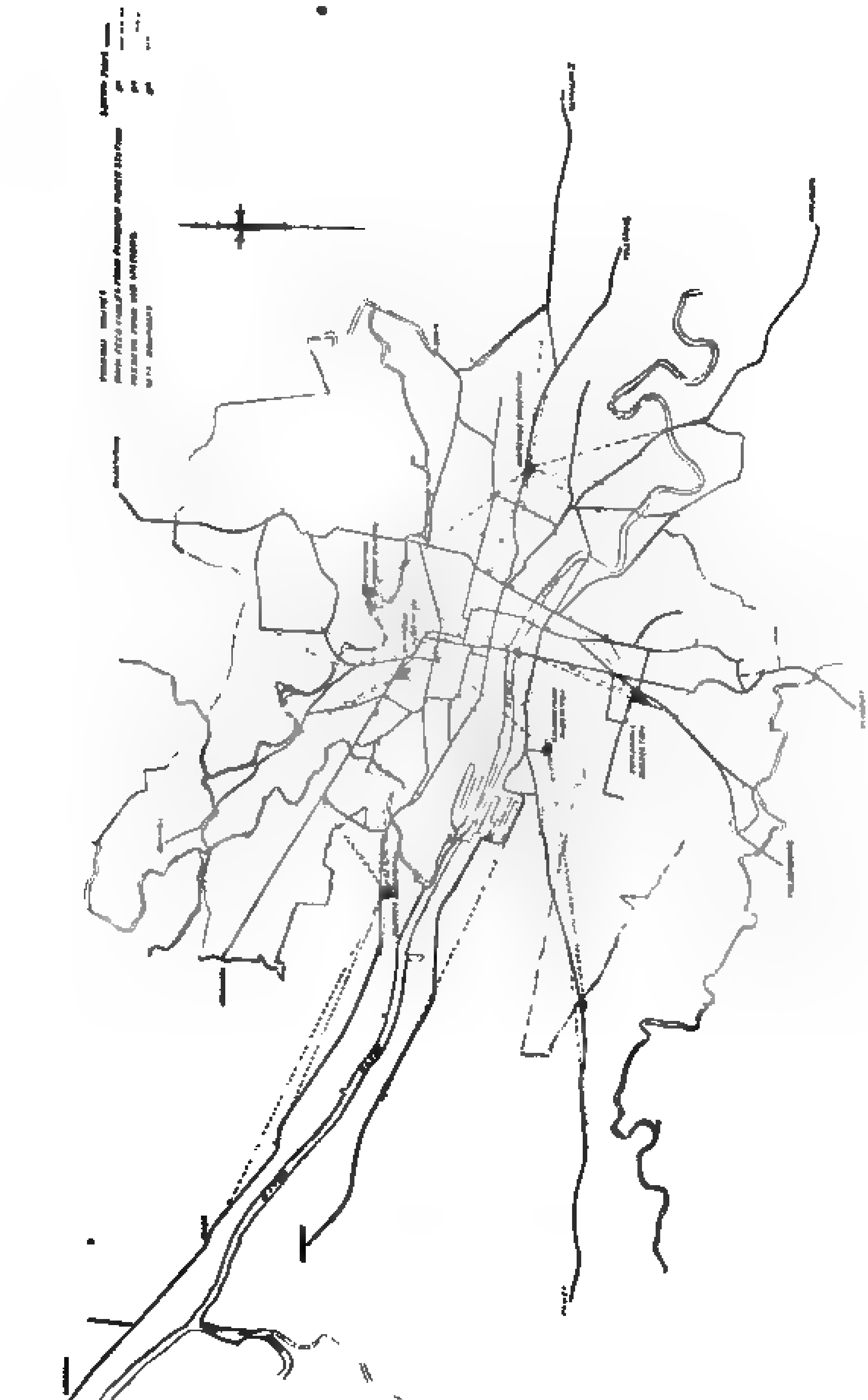


FIG. 75.—Plan of Tramway Routes and Feeder Cables, High-tension and Low-tension, Glasgow.

five sub-stations, as also those of the low-tension main feeders from these sub-stations. In all there are about 400 miles of electric cable used in the Glasgow tramway system.

In each of these sub-stations the units consist of three oil-cooled transformers of 200 kilowatt capacity, connected in mesh for the three phases, and one rotary converter of 500 kilowatt. Each set of three transformers is in a separate brick chamber with an iron door. The primary voltage being 6500, the energy may, at will, be transformed to any of four voltages ranging from 310 to 350. The transformer efficiency is 97½ per cent. at full, and 97 per cent. at half

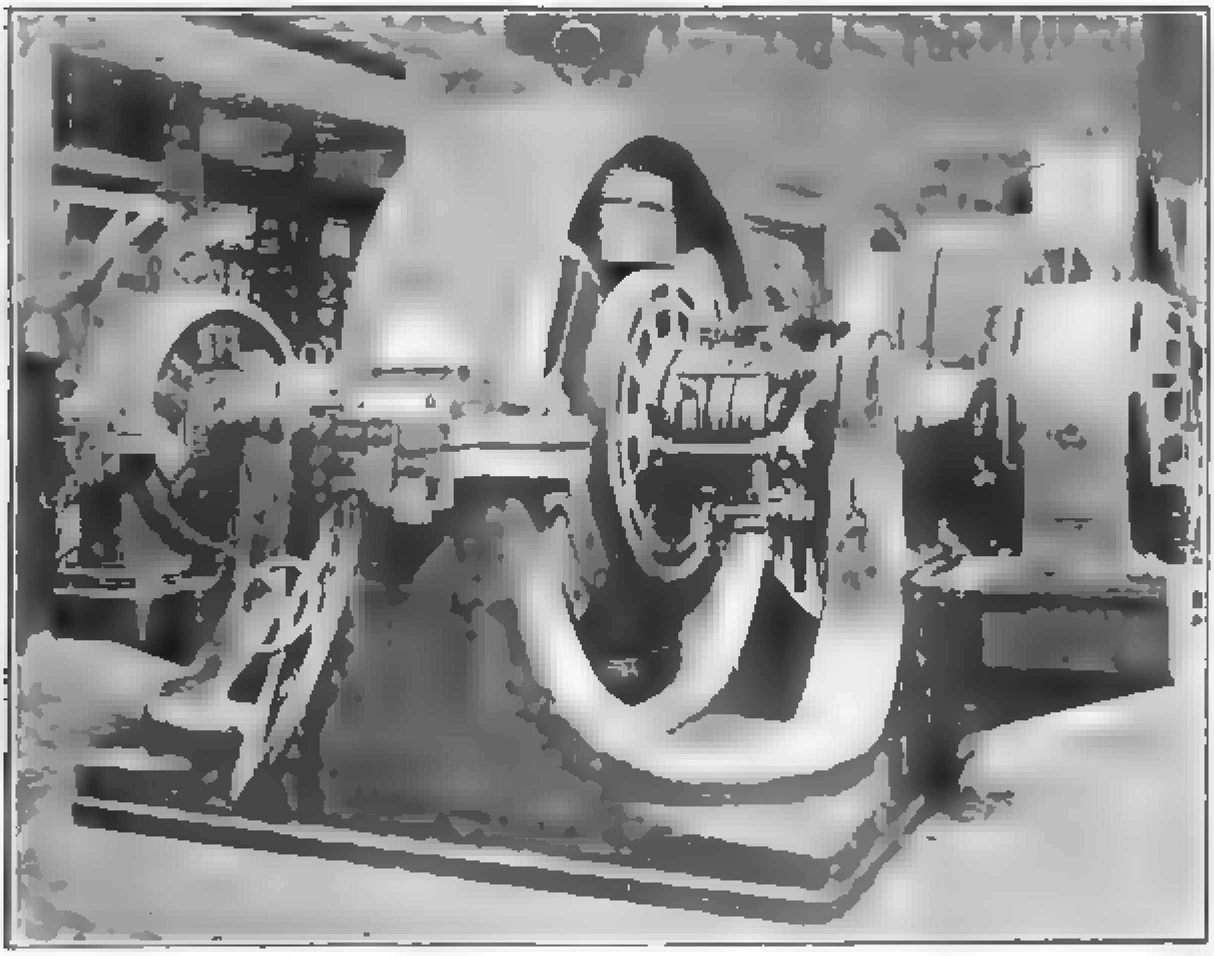


FIG. 76.—Westinghouse 500 K.W. 6-pole Converter, Induction Motor and Booster, A.C. ends.

load. The converters are six-pole machines running at 500 revolutions per minute, and over compounded to raise the voltage from 500 to 550 volts as the load rises to the maximum. The efficiency ranges from 95 at full load to 92½ per cent. at half load. On the same shaft is mounted a booster of 30 kilowatt power at 80 volts to suck current from the rail-return. An induction motor is keyed on the other end of the shaft, whereby the converter is started into motion and run up to synchronous speed before the main supply is switched on to its collector rings. Fig. 76 is a view of a sub-station showing one such unit in the foreground.

Fig. 77 shows more distinctly the other ends of these machines and the switchboard.

There are 5 such units at Coplawhill sub-station; 4 at Kinning Park; 3 at Partick; 7 at Dalhousie; and 5 at Whiteval; in all 24 units, or 12,000 kilowatt delivered from the rotary converters.

38. At the Pinkston Central Power Station there are four main sets: two Allis and two Musgrave engines, and all the generators of British Thomson-Houston make. These generators are direct coupled to their engines, and are each 2500 kilowatt. They are three-phase star-wound, with 6500 volts between each phase at a frequency of

FIG. 77.—Westinghouse Rotary Converters, D.C. ends.

25 per second and a speed of 75 revolutions per minute, they being forty-pole machines. The armature is external and stationary. Its outside diameter is $21\frac{1}{2}$ feet. It carries 120 coils, each of 18 turns. The inductor bars are about $\frac{1}{2}$-inch by $\frac{1}{4}$-inch copper section, and are held in the slots by wooden wedges. The diameter of the rotating field is $16\frac{1}{2}$ feet. The whole weighs 44 tons, of which 38 tons are in the revolving field and shaft. There are 40 field-coils, each of 43 turns, of copper strip $1\frac{3}{8}$-inch wide by $\frac{1}{8}$-inch thick. The normal excitation is 250 ampères at 100 volts. The generator is capable of 50 per cent. overload for 15 minutes without harmful overheating.

There is nothing very particular worth noting here about either

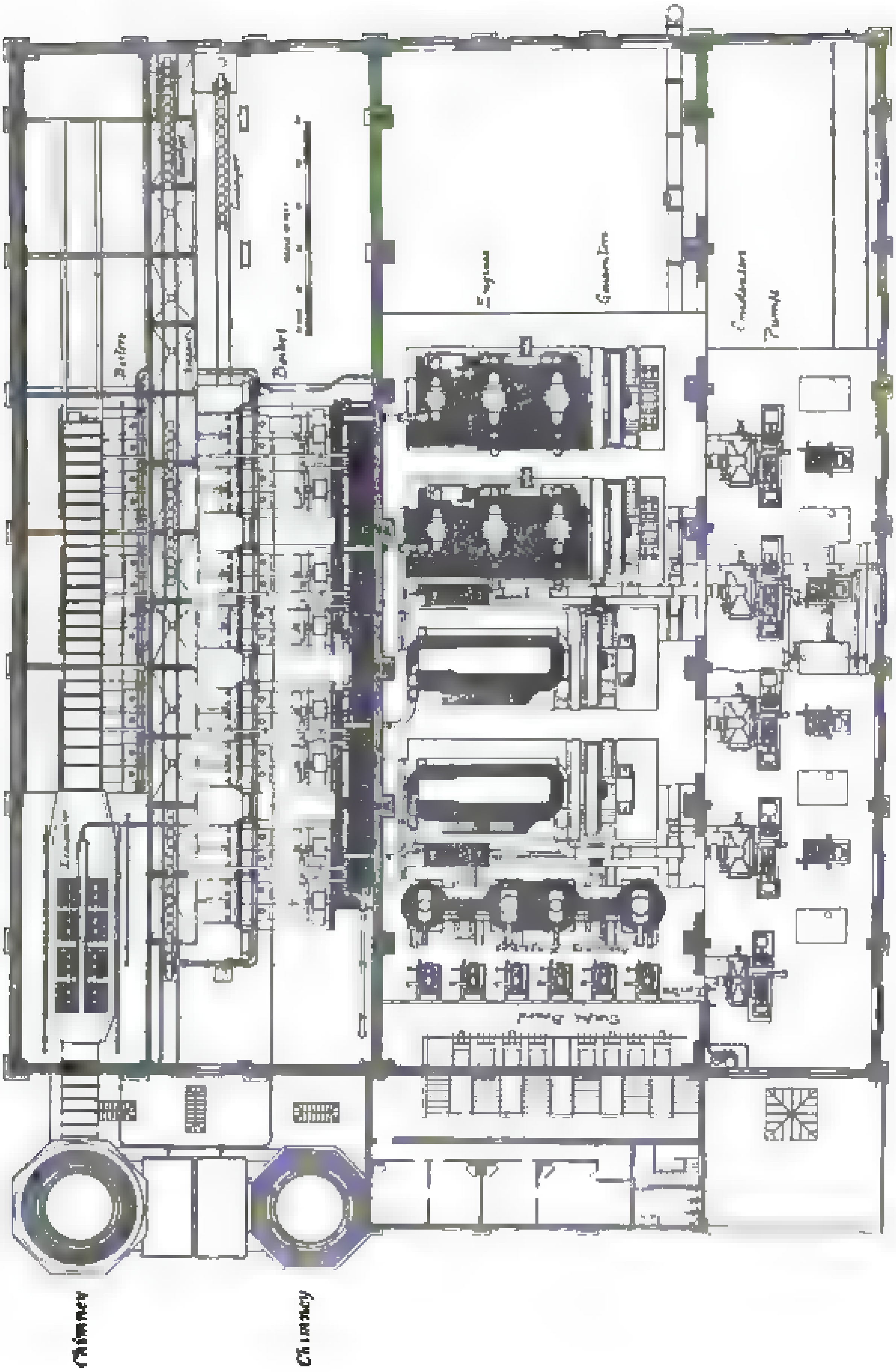


Fig. 78.—Plan of Generating Station, Pinkston, Glasgow.

set of engines. They are three-cylinder vertical compound condensing, with Corliss valve gear, each indicating 4000 horse-power, equivalent to 3000 kilowatt, at 75 revolutions per minute and 150 lbs. per square inch steam pressure. The cylinders are 42 + 62 + 62 inches by 60 inches stroke. To each engine and dynamo there are six main-shaft bearings of the following sizes: 22 by 36 inches, 22 by 36 inches, 24 by 36 inches, 24 by 36 inches, 32 by 64 inches,

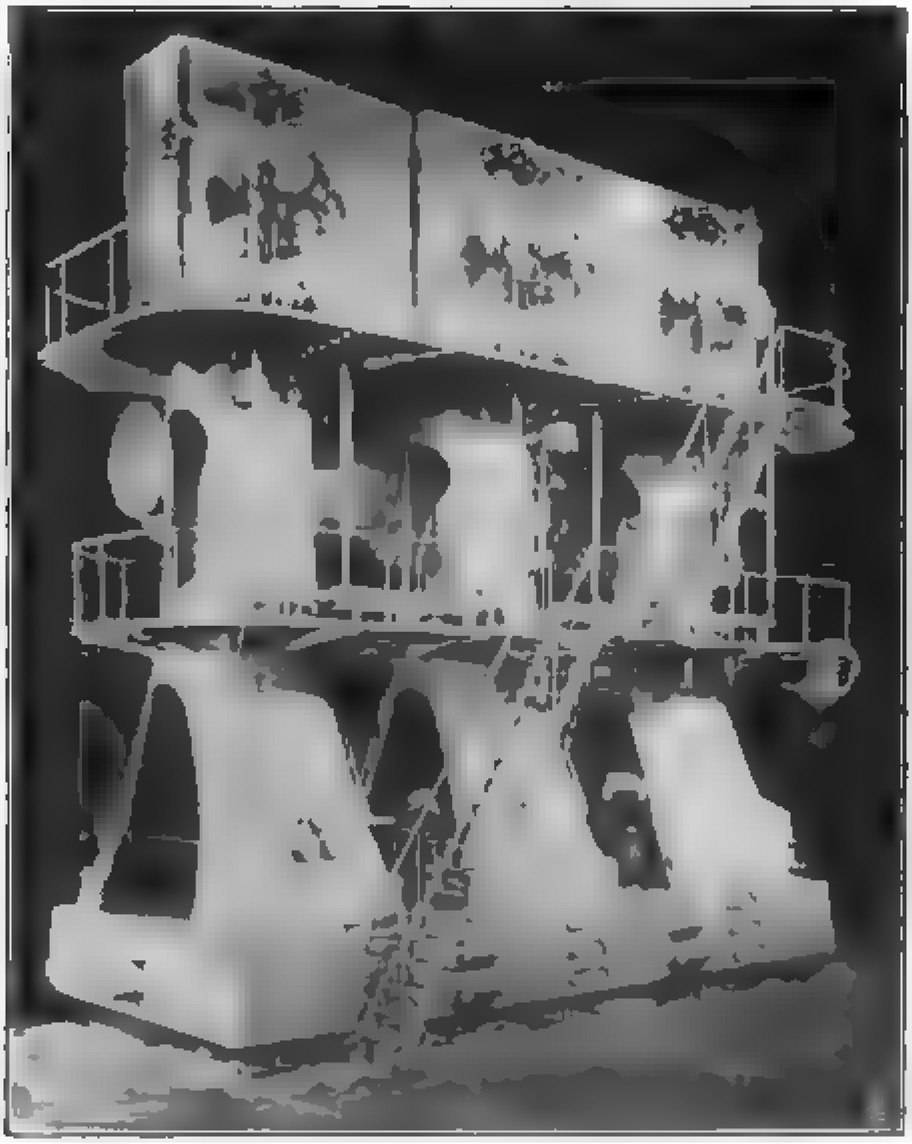


FIG. 79.—Main Engines, Pinkston, Glasgow.

and 30 by 48 inches. Each engine is capable of overload up to 5000 horse-power. The fly-wheel of the Allis engine weighs 105 tons, and that of the Musgrave 145 tons.

There are four surface condensers, each of 60,000 lbs. per hour condensing capacity; and one smaller similar condenser for auxiliary engines to condense 24,000 lbs. per hour.

There are sixteen Babcock and Wilcox water-tube boilers ranged in two lines along either side of the boiler-house. These have 4-inch

tubes 18 feet long, and have each over 5000 square feet heating surface. The steaming capacity of each is 20,000 lbs. per hour at 160 lbs. per square inch, and each is fitted with a superheater.

Fig. 78 is a plan of this Pinkston station. The building is 244 feet long by 200 feet wide, and there are two large chimneys 16 feet diameter inside, 50 feet outside diameter across the octagonal base, and 263 feet high. Of the width, 84 feet is occupied by the boiler-room, 75 feet by the engine and dynamo room, and 40 feet by the auxiliary plant. The ground area is sufficient for a 50 per cent. extension of the plant. The walls are frames of rolled steel-girder filled in with brickwork of plastic clay. The steel columns take all

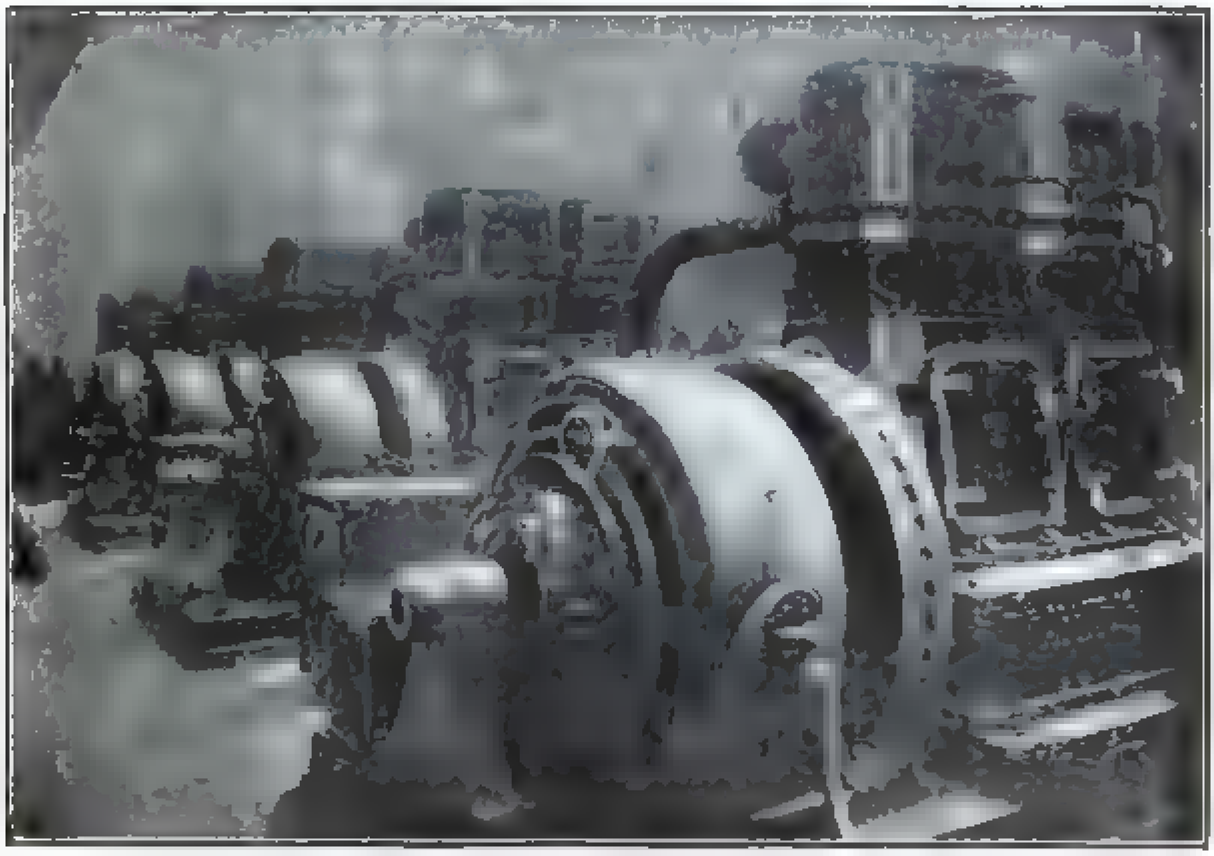


FIG. 80.—Exciter Engines and Dynamos, Pinkston.

the loads, or are sufficiently strong to do so. As seen from the map (Fig. 75) the station occupies a fairly central position. Railway sidings bring the wagons directly over the coal bunkers at two different levels. The lower bunkers hold 3000 tons, and the upper 2400 tons. There are two chain-bucket conveyors, each of which can shift 50 tons of coal per hour. From the overhead bunkers the coal passes through automatic weighing-shoots into the hoppers, and these feed on to chain-grate mechanical stokers of the Babcock and Wilcox pattern, driven by electric motors, the motor shaft running under the floor the whole length of the house. Corporation-main water is used for the feed, supplied through two large steel storage tanks built

between the two chimney stacks, their combined capacity being 360,000 lbs., which is enough for $1\frac{1}{3}$ hour's consumption of the four main engines all working at full load. The full coal-bunker capacity would supply all these engines at full load for between 250 and 300 hours. The circulating water for the condensers is pumped from the Forth and Clyde Canal. The coal chain-conveyors remove the ash and lift it into an overhead ash-bin, from which it is shot into railway trucks. The economizers are sufficient to heat 120,000 lbs. of water per hour to 160° Fahr.

There are two auxiliary vertical cross-compound engines, each of

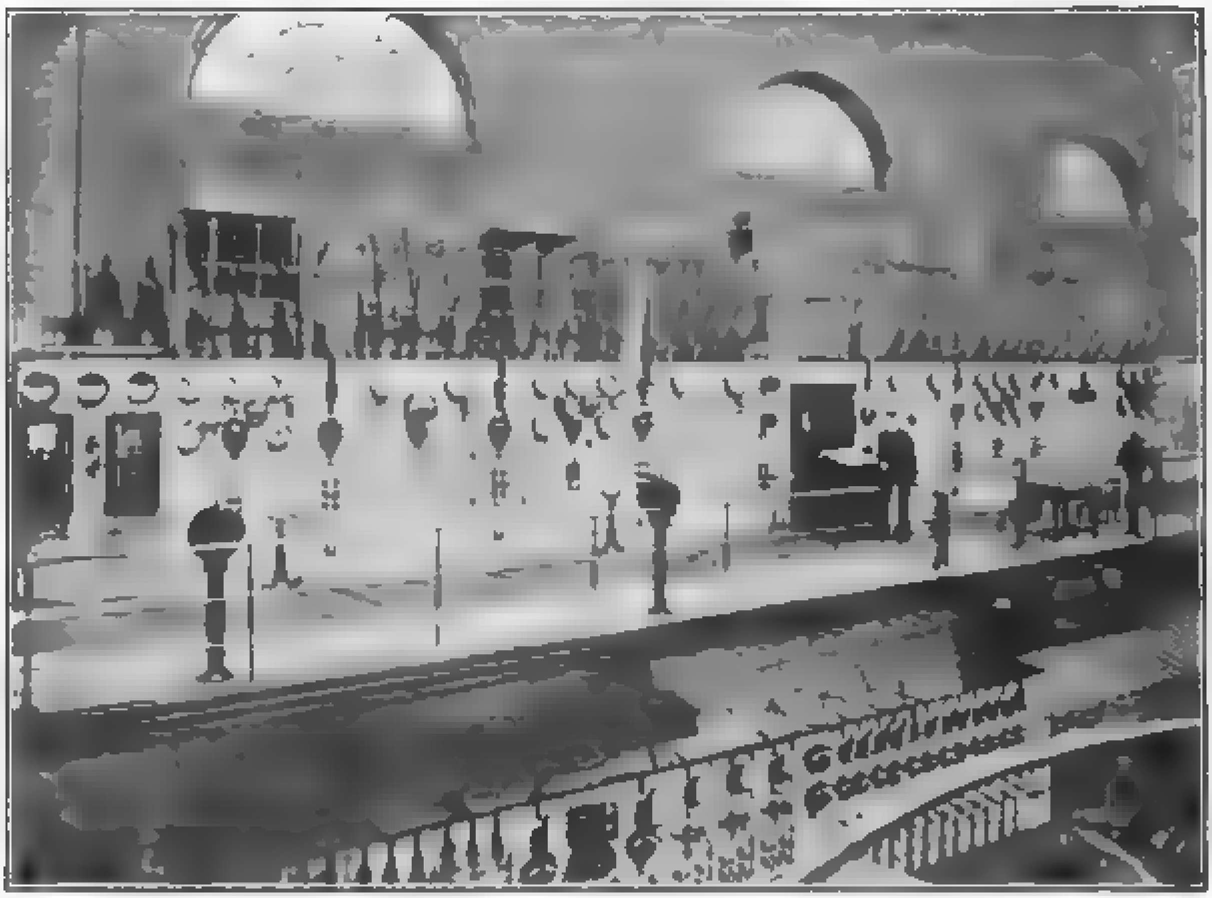


FIG. 81.—Main Switchboard, Pinkston.

800 horse-power normal, whose cylinders are 22 + 44 inches by 42 inches stroke. Besides driving all the auxiliary plant, these engines supply direct-current energy to the sub-stations at night for lighting and subsidiary work. The six exciter engines are vertical enclosed 85-horse-power compound engines running at 300 revolutions per minute, with cylinders 11 + 19 inches by 8 inches stroke. The exciting dynamos are six-pole, working at 100 volts.

39. The plan (Fig. 78) shows that the main switchboard is on a gallery at the exciter end of the engine-room. It contains 34 panels; one for each main generator; one "interconnector" for each generator; one for each exciter; and 20 feeder panels. The latter are in a

separate room outside the main wall, and are in five groups corresponding to the five sub-stations. As already stated, four main cables lead to each sub-station. On each generator panel there is a high-tension three-pole oil switch for 250 ampères, three ammeters, one field-ammeter, one voltmeter, two wattmeters, a voltmeter plug-switch, and a two-pole field-switch. All the main current instruments are worked through transformers by low-tension current. The interconnecting panels also carry three-pole oil switches for 250 ampères at 6500 volts. The main bus-bars have each a copper section $2\frac{1}{2}$ inches by $\frac{3}{4}$ inch. On the feeder panels each outgoing cable has a three-pole high-tension oil switch, and the indicating

FIG 82.—Car-shed, Coplawhill, Glasgow.

instruments are also worked at transformed low tension. Each of these feeder switches is designed to break 150 ampères.

Fig. 79 gives an interesting photographic view of one of the main engines at this power station; while Fig. 80 is a similar view of the row of six exciting engines and dynamos. Fig. 81 shows the upper portion of the main switchboard. Fig. 82 is one of the Corporation's eleven car-sheds, situate in Coplawhill Works, where the Corporation build and repair their own cars.

40. The average price paid at this power station for coal in the year 1903–4 was 6*s.* $7\frac{1}{2}$*d.* per ton for "washed shingles," and the tramway department paid the Corporation 4*d.* per 1000 gallons for

water. The coal used per I.H.P.-hour was 2·693 lbs., and 3·285 lbs. per kilowatt-hour. The steam consumption was 19·02 lbs. water per I.H.P.-hour, or 23·2 lbs. per kilowatt-hour; and the evaporation per lb. of coal was 7·05 lbs.

For this year the power expenses were as given in the following table (XI.). In columns 2 and 3 of the table these are reduced to per kilowatt-hour and to per car-mile.

As the normal working day on the Glasgow tramways is 16 hours, and 16 × 365 = 5840 hours per year, and as 15,372,609 B.T. Units were generated, the energy consumption averaged over the working hours was 2632 kilowatt. Dividing the total annual power costs by this, we obtain the figure £7 14*s.* 0*d.* per kilowatt-year without reckoning in rent, taxes, rates, insurance, depreciation or interest on capital.

Since the full power of the four main generators is 10,000 kilowatt, the load factor reckoned on the 16 hours' working day is 26·3 per cent.

TABLE XI.—STATEMENT OF POWER EXPENSES, GLASGOW CENTRAL STATION, 1903–4.

	Kilowatt-hours.	Car-miles.
Total for year	15,372,609 ...	16,291,082

	Per year. £	s.	d.	Per K.W.-hour.	Per car-mile.
Salaries and wages	8409	16	1	0·1313	0·1239
Fuel	9781	2	9	0·1527	0·1441
Water	878	10	8	0·0137	0·0129
Oil and waste ...	1047	10	3	0·0163	0·0154
Miscellaneous ...	176	8	1	0·0028	0·0026
	20,293	7	10	0·3168	0·2989

41. In the accounts of the department depreciation is allowed for at the following rates:—

Bonding of rails	7½ per cent.
Ducts, cables, poles, and rosettes	3 " "
Section boxes and telephones	5 " "
Buildings	2½ " "
Power station machinery	5 " "
Machine tools	7½ " "
Cars	7½ " "
Sundry equipments	7½ " "
Furniture	7½ " "

This depreciation averages on the whole capital expenditure 2·9 per cent. But an addition to this is made in the "Appropriation Account," under the heading of special or "additional depreciation," which brings this average up to 5·2 per cent. The "additional" depreciation is written off chiefly those values which were the purchase prices of buildings and plant taken over from the previous private tramway company at the time the whole was worked by horse traction, the business being valued as a going concern and much of the value being due to special adaptation to the purposes of horse tramways. It is, of course, necessary to wipe out this special adaptation value as soon as possible.

42. The capital expenditure on which this depreciation is allowed is distributed as set forth in the annexed Table XII. The figures in this table are calculated from the 1903–4 report of the manager, Mr. John Young; but for the reductions to the forms given the author is responsible.

TABLE XII.—GLASGOW TRAMWAYS. CAPITAL OUTLAYS PER MILE OF DOUBLE-TRACK.

	Total expenditure to date 31 May, 1904. Unit £1000.	Ratio to total.	Total outlay per car-mile run in year 1903–4.	Total depreciation, sinking fund, renewal fund, to date 31 May, 1904. Unit £1000.	Ratio of depreciation, etc., to total outlay.
		Per cent.	Pence.		
Ground, 15 sites ...	1·54	4·1	1·59	—	0
Buildings, 15 sites ...	5·95	15·7	6·14	1·31	0·22
Tools and sundry plant	0·26	0·7	0·27	0·09	0·35
Central and sub-station plant	5·51	14·5	5·69	0·95	0·17
Permanent way ...	11·35	30·0	11·75	2·88	0·25
Line electrical equipment	7·86	20·8	8·11	1·75	0·22
Cars	2·93	7·7	3·02	0·62	0·21
Car electrical equipment	2·44	6·5	2·52	0·53	0·22
					mean.
Total ...	37·84	100	39·09	8·13	0·215

The second column shows that the permanent way and line equipment account for over 50 per cent. of the whole, while buildings, station plant, and cars with their electrical equipment, each take about 15 per cent. In column 3 the outlay is reduced to per car-mile run in 1903–4. This totals to 39 pence, a figure very close to

the number of thousands of pounds per route mile, this being nearly £38,000. The total depreciation given in the fourth column, or 21½ per cent., may be taken as having accrued in three years, giving an average of about 7 per cent. per year.

43. The route miles now in operation are 79, or 152 of single track. The number of passengers carried in the year ending 31st May, 1904, was close upon 189 millions, and the traffic revenue £718,000. The car-mileage run was 16·3 millions, or 11½ passengers per car-mile. The mean fare paid was 0·9 penny; the mean distance travelled per passenger about two miles; and the mean number of passengers in a car at one time 23. Thirty per cent. of the passengers pay ½*d.* fare, and contribute one-sixth of the revenue; while 61 per cent. pay 1*d.*, and bring in two-thirds of the revenue. The traffic receipts were 10·6 pence per car-mile in 1903–4, while they were 11·8 in 1900–1. Per car-hour these receipts are 3*s.* 7*d.*, and £1050 per car-year, and £2 17*s.* 6*d.* per car-day. The diminution is due to recent extensions in outlying districts, and the figure is certain to increase again. The extensions added 60 per cent. to the route-mileage, and 65 per cent. to the car-mileage. The average number of cars actually running during the 16 hours' working day averages 6·8 per mile of double track, and this is only two-thirds of all the cars in use, there being now 782 cars owned by the Corporation. This number is just under 10 per route-mile. Each car, while it is actually running, earns an average of 6*s.* per hour. The energy consumption is 940 watt-hours per car-mile, ranging from 860 to 1030 watt-hours.

Throughout the year the passenger-load per week varies in the ratio 85 to 100; the money receipts in the ratio, 82 to 100; and the energy consumption in the ratio, 76 to 100. The mean weekly mileage run has risen 10 per cent. during the year.

44. The energy consumption is a very small part of the total cost —only 0·3*d.* per car-mile and 4·1 per cent. of the total working costs, of which half is accounted for by the coal bill. Of this total nearly 35 per cent. is spent on wages, salaries, and fees, and nearly 42 per cent. on repairs, track renewal, and depreciation.

Taken per car-mile, these working costs are thus classified:—

	Pence per car-mile.
Power	0·30
Traffic expenses	2·91
General expenses	1·04
Repairs	1·01
Track renewal	0·90
Depreciation	1·15
Total	7·31
Or without depreciation	6·16

Thus the traffic expenses about equal the general expenses and the repairs and renewals, and these together are 80 per cent. of the working costs. It is thus seen that economic traffic management and minimization of "general expenses" dominate the whole problem of successful working, and that economy in power expenditure is of relatively little consequence. But in the traffic expenses wages of motor-men, conductors, and other servants account for 2·11 out of the 2·91 pence, while cleaning and oiling the cars takes 0·25 penny. The former can hardly be reduced, while the latter item can certainly not be halved. There is thus no possibility of reducing the traffic costs by so much as $\frac{1}{2}d.$ Again, over half the "general expenses" are taxes, while taxes and insurances together make up more than 80 per cent. of the whole, leaving less than $\frac{1}{4}d.$ per car-mile on which possible economy might be practised. In repairs and renewals, amounting together to 1·91 pence, reductions might, no doubt, be possible if the plant were more perfect than it is; but such more perfect plant would cost more in capital outlay. It may be explained that the £61,000 for track renewals is a sum paid to a "Permanent Way Renewals Fund," at the rate, fixed by resolution of the Council, of £900 per mile of double track. Only £4600 of this sum was actually expended during the year. This fund, which is a reserve fund for perpetual upkeep, stands now at the figure of £193,000 after deduction of all actual expenditure out of it, or £2760 per double mile; while the total cost of construction has been £10,400 per mile, or four times as much as the renewal fund.

CHAPTER V

CONDUIT TRAMWAYS

1. THE first conduit tramways in England were laid in Blackpool, and were designed by Mr. Holroyd Smith. The slot, $\frac{5}{8}$ inch wide, lay in the centre of the track, and the conduit was a cast-iron tube. The return current was by the track-rails, and the supply current by a pair of rails of semi-elliptical tube section. This conductor was split for the sake of symmetry in the forces acting upon the collector, which consisted of two sliding plates pressed outwards horizontally by springs. Part of the line passes along the beach, and in rough weather with high tides is washed over by seawater and sand. For such a situation the conduit system was an unfortunate choice, and it had therefore little or no chance of being economically worked. The electrical management subsequently passed into the hands of Mr. Thomas Parker of Wolverhampton, and the traffic is still carried on vigorously.

2. The first important conduit tramways were laid in Buda-Pesth, a city which has long led in the vanguard in matters electrical. Pesth is one of the most picturesque cities of Eastern Europe, and its inhabitants will allow no overhead wires to damage the beauties of the streets inside the city boundaries. The first tramways here were built to the design of Siemens and Halske.

As seen in Fig. 83, one of each pair of running rails is slotted, or rather the slot is formed by using separate running and guard rails on one side of the track, the space between them serving as grooves for the tyre-flanges of the wheels and also as slot opening into the conduit below.

In this side-slot system with the conduit immediately below the rail, the necessity of having a very solid and rigid foundation for the running rail leads to a massive and comparatively costly construction of conduit, and this largely neutralizes the economical advantage of dispensing with a third slotted rail.

Fig. 84 is a section of the Pesth conduit showing the form of

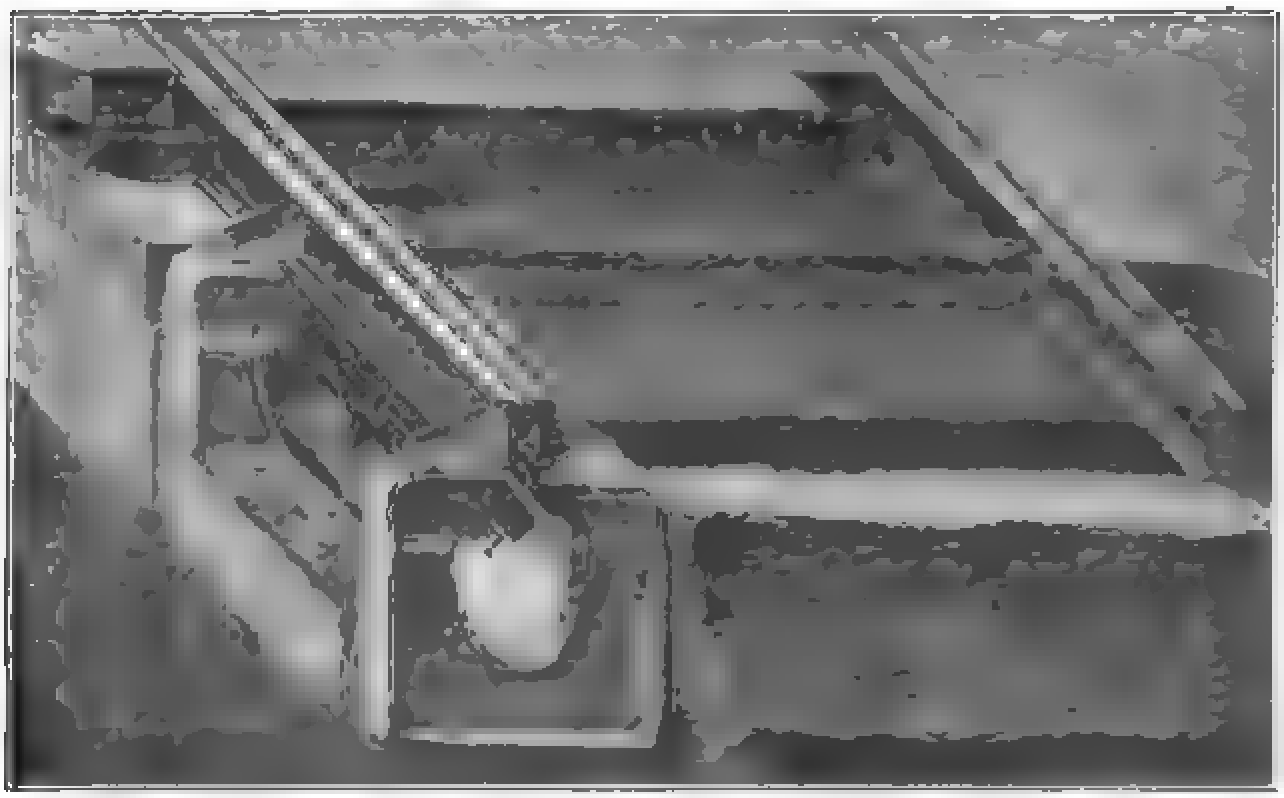


FIG. 83.—Photographic view of Buda-Pesth Side-slot Conduit Tramway.

conductor-rails now used. Fig. 85 shows the first form of conductor and insulating suspension used. The slot is $1\frac{1}{4}$ inch wide. The conduit is 11 inches wide by $13\frac{1}{2}$ inches inside depth to top of yoke, with 6-inch depth of rail above this. The depth of metal at the base of the yoke is 5 inches, so that from rail top-face to the sole of the yoke there is $24\frac{1}{2}$ inches depth. The conduit is of ovaloid shape and is built in concrete laid round a sheet-steel tube, which is withdrawn when the concrete has set. Spaced about 4 feet apart are cast-iron "yokes," to which the rails are secured and which are necessary to prevent the slot closing under the pressure of the roadway, portions of the material of which swell and shrink with change of wetness. This tendency to close under this

lateral pressure is much increased by the trembling caused by the traffic, both tram-car and ordinary. Naturally a slot lying immediately under the track of the car-wheels suffers more from this cause, and has to be better supported against it, than does one laid along the centre line of the track. The width of metal at each side of the Pesth yoke is 6 inches, and beyond this extends on either side a 4-inch wing-bracket which lies on a longitudinal I girder 13 inches deep. The rails are 6 inches deep with $1\frac{3}{4}$-inch width of top-face and $3\frac{1}{2}$

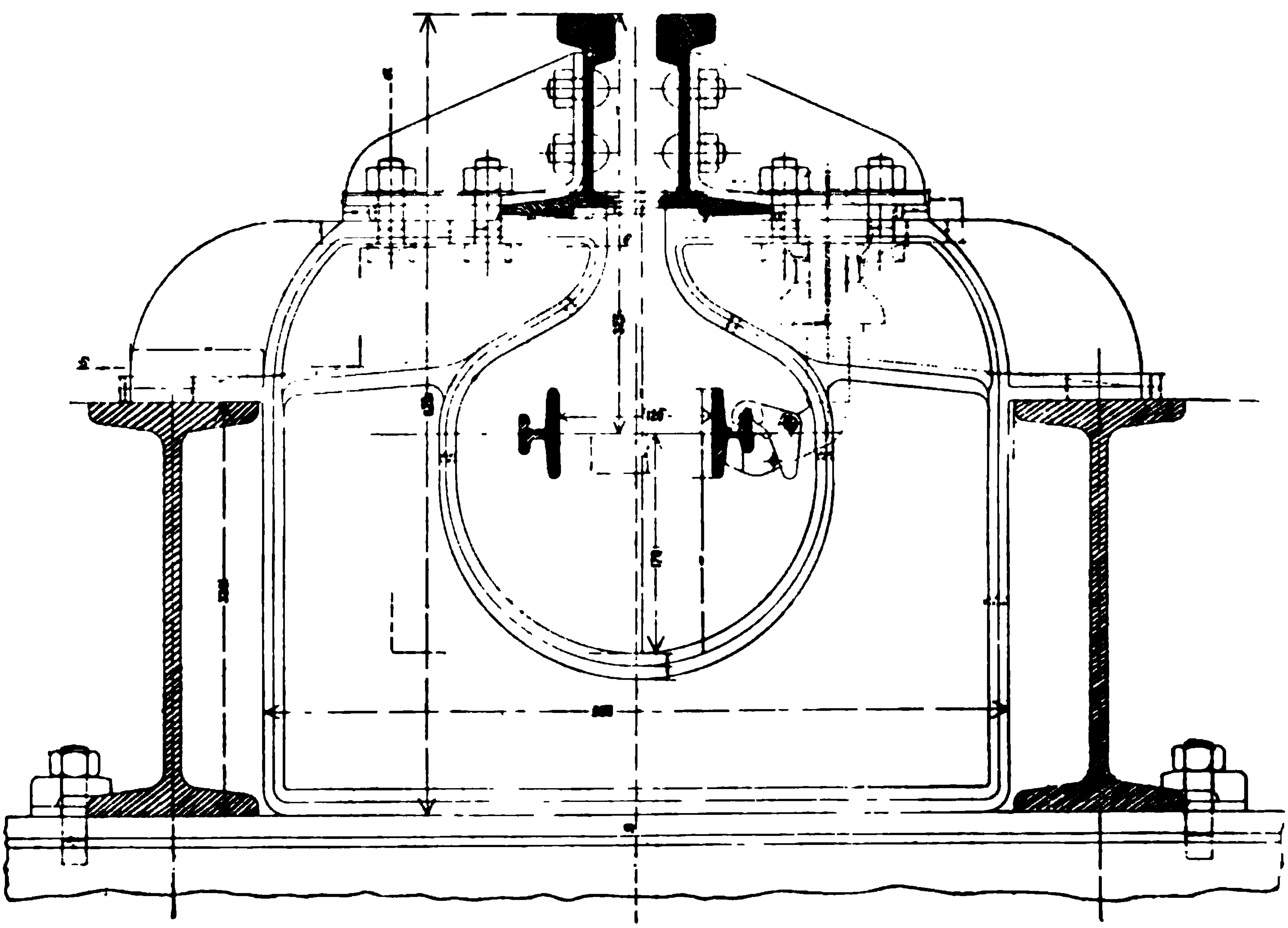


FIG. 84.—Buda-Pesth Conduit, Slot and Conductor Rails, and Insulators.

inches wide bottom flange. They weigh 85 lbs. per yard, or 170 lbs. for the pair forming the slot. At the other side of the track two rails of the same section form between them the running surface and the groove. Each rail of the slot is rolled with a $\frac{1}{4}$ inch inset on its bottom flange fitting over a 1-inch wide projection cast on the top of the yoke. The rail is secured to the yoke by cast-iron angle-brackets with two rivet-head bolts through the rail-web and two bolts through the top flange of the yoke.

This construction, and its dimensions, are extremely instructive

and interesting in comparison with those of the most recent conduits as given below. The Pesth conduit was the first constructed, and if it had to be rebuilt now it would be designed on less costly lines.

3. The insulators are secured to the rail away from the yoke. In the early construction, shown in Fig. 85, the insulating material is a form of ebonite, interposed between an outside protecting cast-iron bell and bracket and an interior suspension bolt of iron. The conducting rails were angle-steels with equal $2\frac{3}{8}$-inch legs by $\frac{5}{16}$ inch thick, these being clamped in a Y-fork bracket by an ingenious two-pin lever-clamp. The smaller pin is a split pin easily withdrawn, and when it is pulled out the lever is free to be raised, and the rail can then be lifted out.

This form of conductor-rail evidently requires a very easy vertical spring suspension of the sliding contact blocks carried by the plough on the car, because at each instant the rail specifies rigidly the level at which each contact block must hang. This form was therefore abandoned in favour of that shown in Fig. 84, the contact face of which is vertical and $2\frac{3}{4}$ inches deep. This squat I-section steel rail, of $1\frac{1}{4}$-inch horizontal width, is held to the insulator by a clamp of similar principle to the other, the clamp-lever being now bell-cranked. The insulator is shown in dotted line on the right of the drawing. It is bolted to the vertical web of the slot-rail.

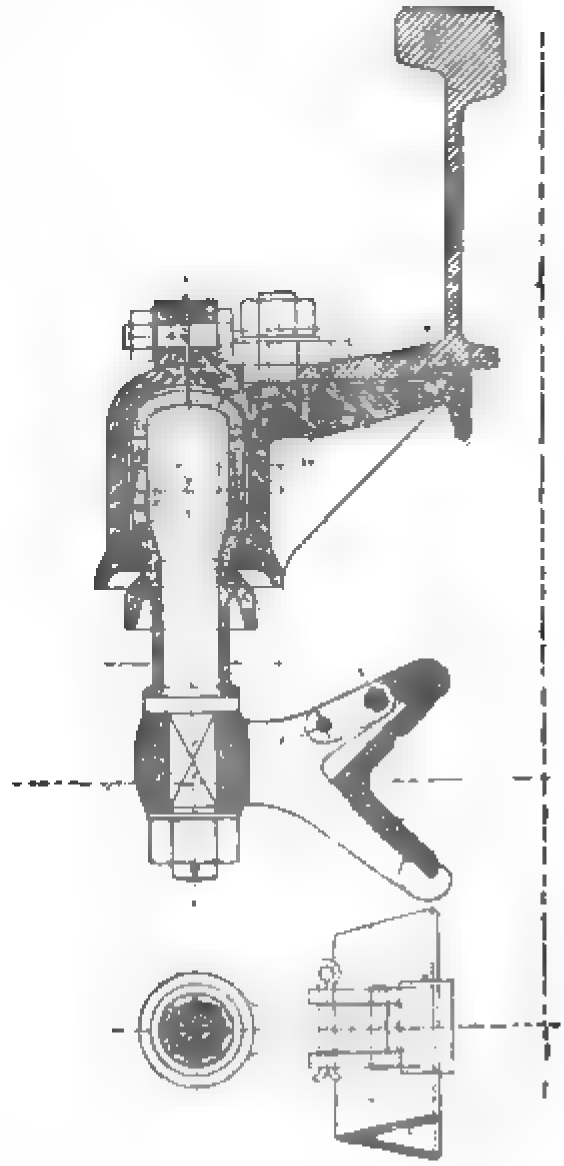


FIG. 85.—Pesth Conduit. Early design.

The insulating material is porcelain, into which is screwed a steel bolt, the outer protecting bell and suspending bracket being of cast iron.

The faces of the two conductor-rails are 120 mm. or $4\frac{3}{4}$ inches, apart. The one carries the outward, and the other the return, current. The running rails form no part of the electric circuit. The back of the conductor-rail stands 50 mm. or nearly 2 inches, distant from the yoke, which is, of course, at earth potential, this air space giving ample insulation, as the voltage is about 550 only.

4. Messrs. Siemens and Halske have employed this side-slot design, modified in detail and in dimensions, on the tramways both of Dresden and of Berlin. Practically the same system is employed also in Vienna. The yokes are placed about 4 feet apart, and the conduit is $13\frac{1}{2}$ inches wide and 18 inches deep inside. The conduit is drained to the sewers at spacings averaging about 160 feet. Plain T-section conducting rails are used, placed $4\frac{3}{4}$ inches apart. They are suspended from the slot-rail web at points intermediate between the yokes, there being one insulating suspension for every three yokes in straight runs and for every two yokes on curves.

The current collector or plough is composed of two parts, one picking up current from the +, and the other discharging the return current to the −, conductor. The two parts lie tandem and are bound together at their bases. One half is shown in side view and sectional elevation in Fig. 86. The plough is lowered into the conduit by running it down an inclined plane from the groove of the ordinary overhead tram-rails, these installations running by overhead conductors outside certain city limits and using the conduit traction only in the main streets. The wheel mounted on the bottom toe of the plough gives support in running down this incline, and also in ascending a similar incline in passing from conduit to overhead. The body of the plough is composed of a central thin strip of copper, on each side of which comes a layer of insulation with an outside sheet-steel shield on either face. The contact piece is a sliding plate of bronze hinged on a horizontal fore-and-aft pin, round which is wound a spiral spring which throws the plate towards the horizontal position. Above the slot rails there are mounted on the plough body four small grooved guide-rollers, which run between vertical guide-bars on the under-frame of the truck. From the conductor's platform, by means of a chain and ratchet gear, the plough can be raised or lowered by the conductor.

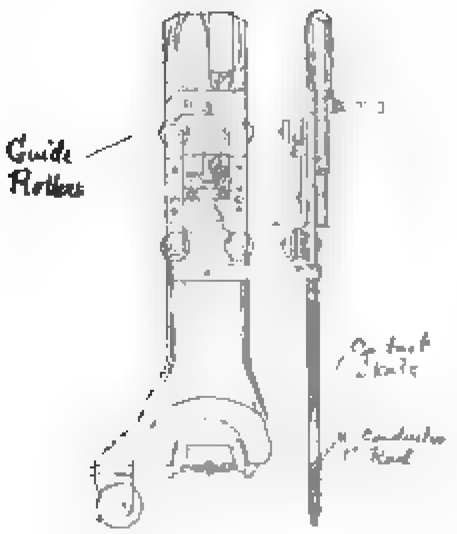


FIG. 86.—Siemens and Halske Side-slot Plough.

5. Messrs. Waller and Manville patented a conduit system which considerably reduces the cost of construction. The slot and the conduit are directly under one of the track-rails as in Pesth, and the return current passes by these rails and the earth. The out conductor is a flexible copper wire like that of overhead tramways. It lies stretched over hook-shaped supports projecting from insulators fastened in the conduit. As a car passes, it picks up the conducting wire to a level some inches higher than these supports. It is picked up by a hooked

sliding collecting plate carried on the lower edge of a plough slung from the car. The lower edge of this collector-hook has to pass over the fixed supporting hook, so that the lift given to the wire is considerable even at the supports, and midway between the supports it is still greater by the sag of the wire. The frictional resistance at the sliding contact must be considerable. This could be reduced by using a roller contact, but this would necessarily increase the height through which the wire must be lifted. The system has been given the name "Simplex," and it is commercially exploited by the "British Insulated Wire Co."

6. The first conduit tried in New York was laid in 1893 upon a design by Mr. Love. The yokes are very heavy, and their base is 31 inches below rail-level, the depth of conduit below rail-level being 24½ inches. The conduit, which is central to the track, is itself a cast-iron tube. Both out and return currents are insulated and are carried by bulb I-section copper wire. Small trolley-wheels are used as collectors, these running underneath the conductor-wires and being mounted on the plough by a vertically elastic suspension.

7. At an early date this design was revised by Mr. Connett, the iron tube being replaced by one in concrete, and stiff iron T-section rails being substituted for the copper-wire conductors.

Most of the conduits in America have been constructed by the Thomson-Houston Co., who, under the title "Union Elektricitäts Gesellschaft," have also built tramways on practically the same design in Paris from the Bastille to Charenton, and in Lyons and Bordeaux. The yokes are spaced 4 feet 8 inches apart, while the inside dimensions of the concrete conduit are 18 inches wide by 20 inches deep. The slot is 1 inch or ⅞ inch wide in America, and is made between two ┘└ shaped rails, which are bolted to the yoke at the bottom flange and tied back to the extended wing brackets of the yoke from the top of the web. In Brussels and elsewhere on the Continent a slot-width of 1¼ inch has been permitted. The conductor-rails have a plain T section, their faces being 6 inches apart. They are supported by porcelain insulators with cast-iron hoods bolted to the slot-rails. The detail of the construction is shown in Fig. 87. On the Continent an I-section rail with rounded head is used as conductor. The current collector, or plough, is very similar to that used on the South London trams, the latest form of which is illustrated below.

8. The points and crossings of central-slot tramways are easier to design, and give less trouble in working, than those for side slots. At the point the side slot makes it very difficult to obtain substantial support for the tongue of the track-rails. This is one of the main reasons why in the United States and in London and Paris the former has been preferred. The side slot also, coming, as it does, immediately

under one wheel, is said to collect more mud in the conduit than does the centre slot, which latter has the advantage of being placed at a slightly higher level—about ⅛ inch—than the track-rails, so that rain-water is shed to either side of the slot. Probably also less noise arises from the rolling of the cars on the track-rails when the hollow conduit is removed from the immediate proximity of either running rail, and the insulators are subjected to somewhat less vibration.

It is to be noted, however, that while the London County Council have chosen the central slot, the only other modern conduit tramway in Britain, namely that at Bournemouth, has been constructed with a side slot, and that it is working satisfactorily.

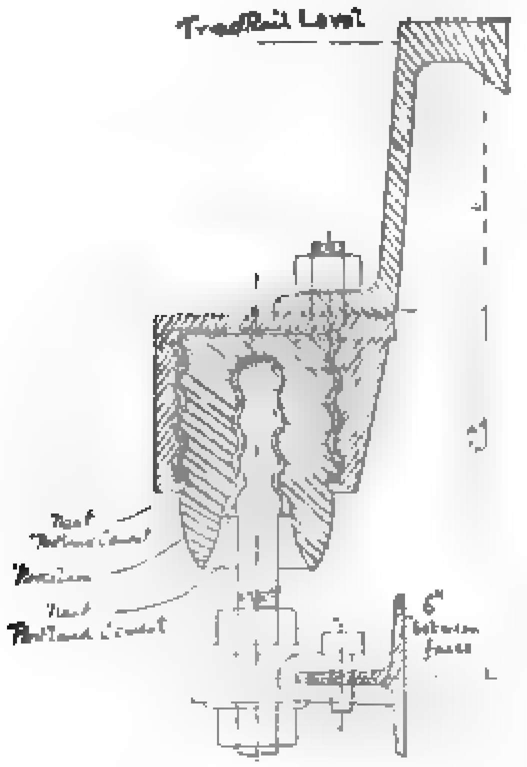
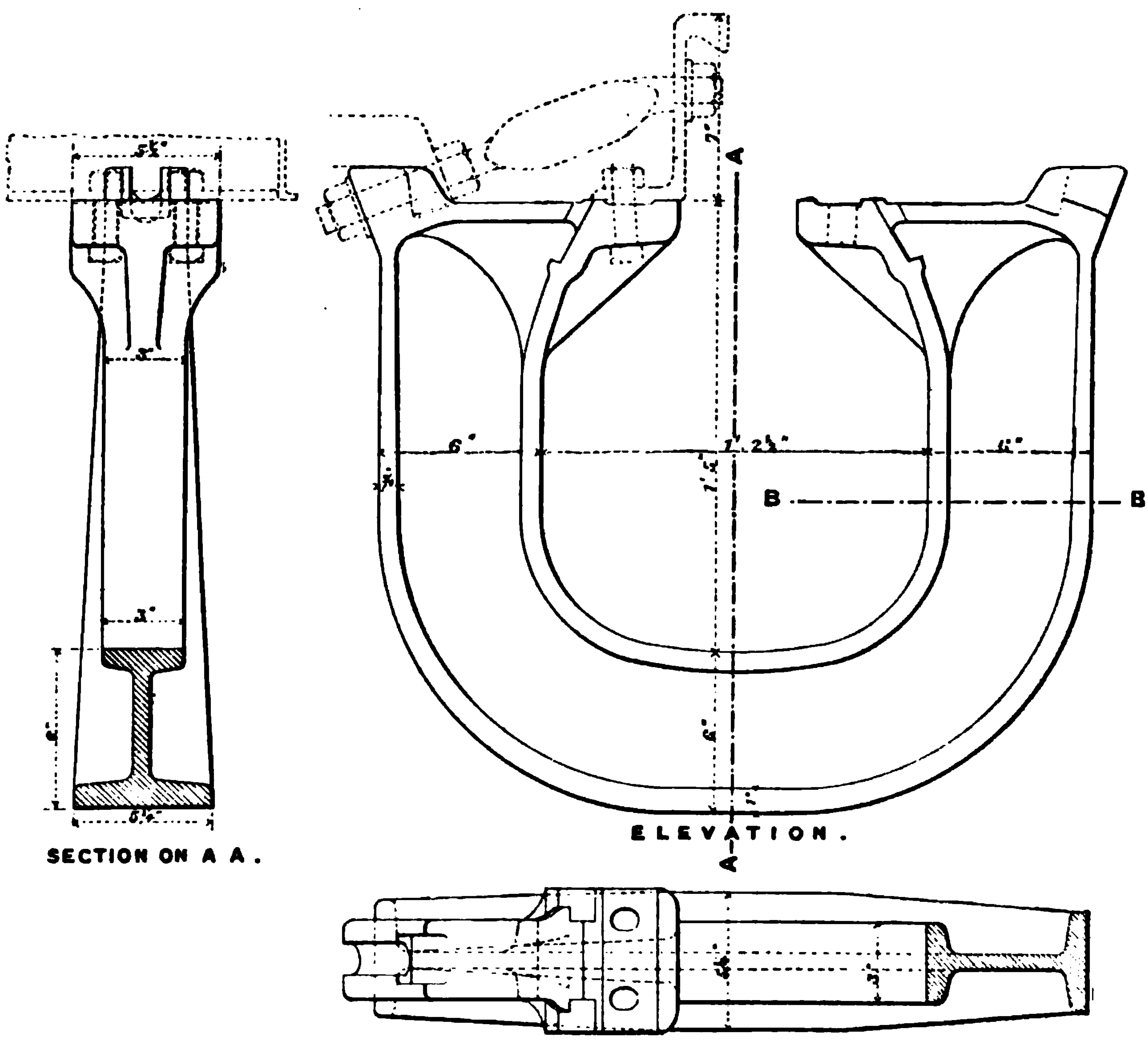


Fig. 87.—Thomson-Houston Central-slot Conductor-rail and Insulators.

9. In October, 1898, Mr. Councillor J. Allen Baker presented to the Highways Committee of the London County Council a lengthy report upon the choice of electric traction system to be used on the Metropolitan Tramways, embodying in it the results of his investigations of many installations in this country, on the Continent, and in America. He recommended the central-slot conduit system, and in June, 1899, Dr. Alexander B. W. Kennedy, who had been called in to give expert advice on the question, agreed in this recommendation so far as lines in the central parts of the district were concerned, while overhead lines were suggested for the outlying suburbs. In the spring of 1902 there was commenced the work of electrification of what were regarded as experimental lengths, in all 8½ route-miles, from Tooting to Westminster and Blackfriars Bridges, and from St. George's Circus to Waterloo Road. These lengths were constructed to the designs and under the supervision of Dr. Kennedy, acting as consulting engineer, by the contractors, Messrs. J. G. White & Co., portions of the work being specially under the direction of Mr. J. H. Rider, the L.C.C. electrical engineer, who has had chief charge of the electrical working of all the lines since opened. These preliminary lines were opened for traffic on May 15, 1903, by His Royal Highness the Prince of Wales. Since then the many further extensions already mentioned in Chapter II. have been carried out to the designs and specifications of Mr. Maurice Fitzmaurice, C.M.G.

Chief Engineer to the L.C.C., assisted by Mr. Rider. Experience on the first lines have suggested many detail improvements, and, therefore, the last length built, namely that from Kennington to Streatham, will alone be here described.

10. The contractors were Messrs. White & Co., and the contract price amounted to £13,000 per mile. The single-track mileage is



CONDUIT YOKE.

FIG. 88.

7½, and the length of route 3 miles 1167 yards. The work was begun on March 28, and finished on June 18, 1904, thus occupying 11 weeks or only 9 days per mile, excluding Sundays upon which no work was done. This was three weeks under contract time.

On the up, or east, side of the long Brixton Hill incline a new wagon-way of two tracks of smooth-faced granite blocks about 10 inches wide was laid to help the heavy traffic uphill and keep it off the tram-rails.

11. Fig. 88 shows in plan and two elevations the yoke used. Its inside size is 14½ inches wide by 17 inches deep, the bottom of the conduit being 24 inches below rail-level and the rail 7 inches deep. The bottom depth and the flank widths of the yoke are 6 inches, and the inside and outside flanges respectively 3 inches and 5¼ inches wide. It is bedded on 4 inches of concrete, so that the depth of excavation needed is 34 inches at the yokes and about 30 inches between the yokes. The normal spacing of the yokes from centre to centre is 45 inches. When this trench is excavated the yokes are put in place, and these are, at suitable intervals, packed up into true alignment and true level according to the prescribed gradient. The slot-rails are then bolted to those yokes that have thus been packed up into true position, and nextly the remainder of the yokes are suspended by being bolted to the rails. Under the yokes thus suspended, the trench is now filled with "5 to 1" concrete, which is

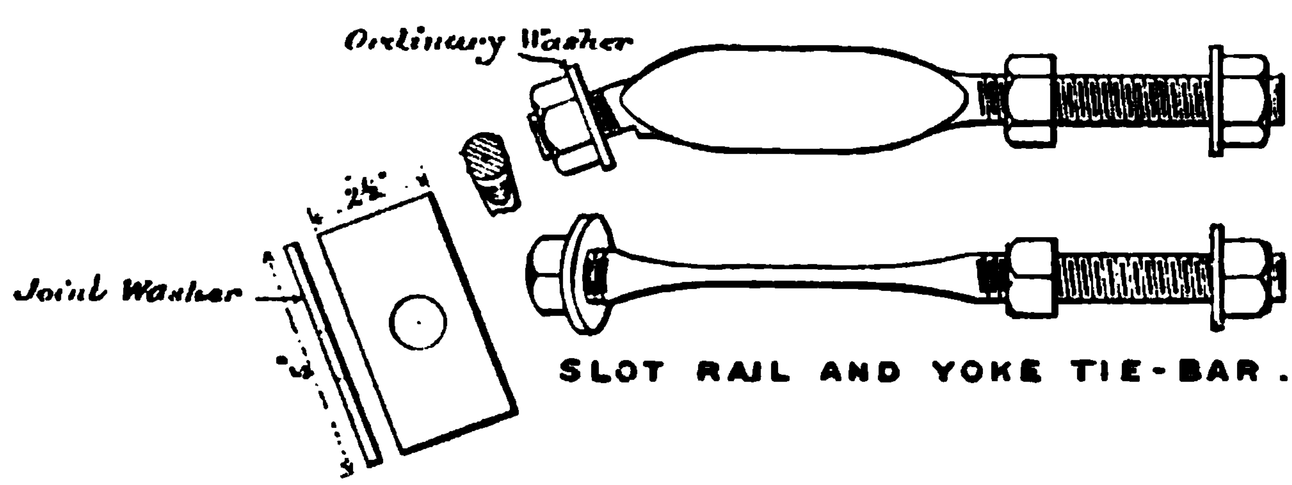


FIG. 89.

rammed in hard. As soon as this is set the packing under the first aligned yokes is removed, and the trench under these similarly filled with rammed concrete. The conduit is now built between the yokes with the same quality of concrete laid in round a steel plate former which stretches from one yoke to the next and rests upon the yokes. This former is collapsible, and, as soon as the concrete round it has set, it is taken out and removed to a new position for a repetition of the same process, so extending the length of built concrete. This process is begun and carried on simultaneously at many points along the line; and at each working end new concrete should be laid in before the old has set hard, otherwise the new and the old will not bind together properly.

12. As seen in Fig. 88, the slot-rail is held back by a tie-bar, the form of which is shown in Fig. 89, to a lug on the outer edge of the yoke. This lug is formed as an open jaw, into which the end of the tie is dropped from above. These ties are laid in loosely during the above filling of the trench, and are adjusted only after the concrete of the conduit thus built has been left at least ten days to set

hard. Meantime the excavations for the 8-inch concrete beds of the track-rails have been made, and the beds themselves, of 7 to 1 concrete, consolidated. The top surface of these beds is floated with 1-inch thickness of cement, in which the track-rails are embedded. Each track-rail is kept to gauge with the yoke and the conduit slot by a tie-bar shown in Fig. 90. The screwed end of this tie is bolted through the web of the rail, and its forked end is jammed over the lug on the side of the yoke and over the shank of the short tie, Fig. 89, between this lug and the slot-rail. Both ties are secured on this lug by the two nuts upon the shank of the shorter one. The duty of the two short ties is to keep the two slot-rails apart the correct distance, namely $\frac{3}{4}$ inch, the prescribed width of slot; the duty of the two long ties is to keep to correct gauge the prescribed distances apart of the two track-rails and the slot.

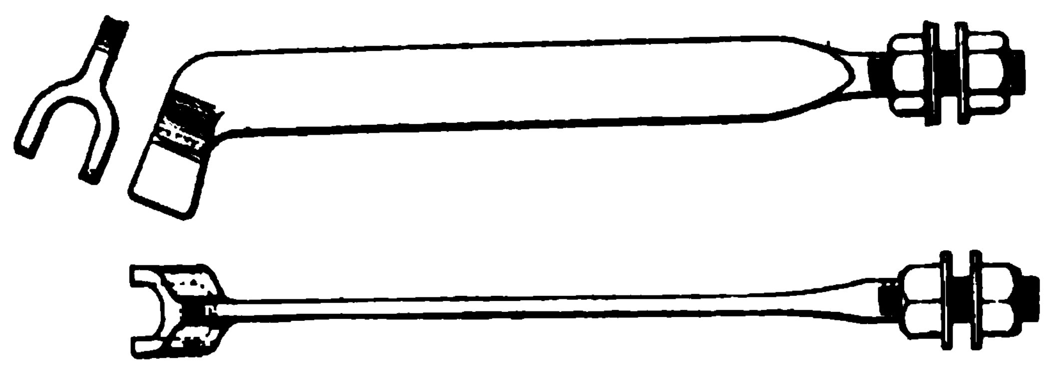
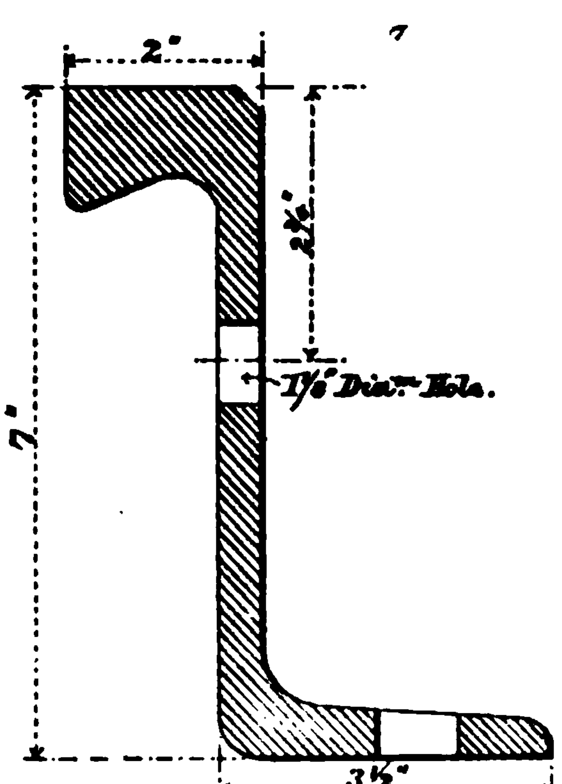


FIG. 90.—Track-rail and Yoke Tie-bar.

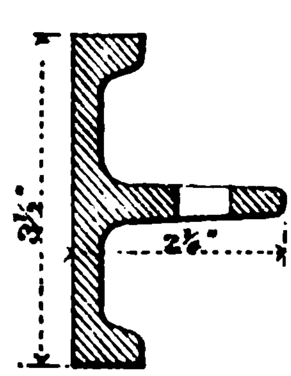
After these adjustments are made the whole width of the roadway to 18 inches outside track-rails is paved with granite-setts bedded on an 8-inch layer of concrete, the interstices being half filled with pitch and grouted with cement and granite chips.

Figs. 91 and 92 show the sections of the slot-rail and of the conductor rail. The top face of the former is 2 inches wide. The extra 4-inch width of iron surface presented on the roadway by these two rails forms one of the main objections raised to the system of central-slot trams.



SECTION OF SLOT-RAIL.

FIG. 91.



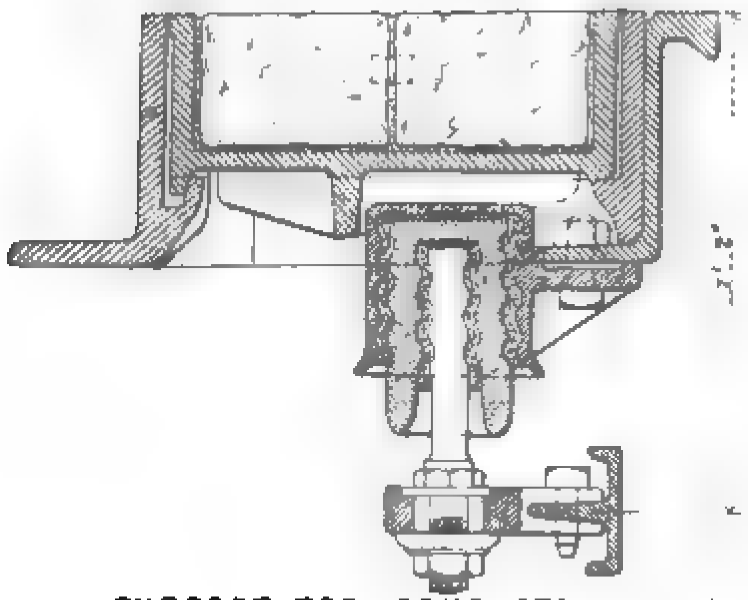
SECTION OF CONDUCTOR-BAR.

FIG. 92.

13. The face of the conductor-rail is $3\frac{1}{2}$ inches deep, and the two faces are placed 6 inches apart. These rails weigh $21\frac{1}{2}$ lbs. per yard,

and are suspended by porcelain insulators, shown in Fig. 93, which are bolted to the base flanges of the slot-rails. They are rolled in 30-feet lengths, and the insulating supports are spaced about 15 feet apart, or three to each rail length. The clamping bracket on the foot of the insulator-bolt is forked, and the web of the **T**-rail is secured in the fork by a pin dropped in from above. Each rail has a section of 2·15 square inches, equivalent to from 0·26 to 0·3 square inch copper section. They are bonded by two stranded copper bonds each 0·108 square inch in section.

The centres of these rails are 14½ inches below rail-level, and the clear air space between their outer edges and the concrete walls of the conduit is 2 inches. Under their lower edges there is a clear depth of 8 inches to the floor.



SUPPORT FOR CONDUCTOR-BARS.

FIG. 93.

The slot-rails are not fish-plated at their joints. Their fastening to the yokes is amply sufficient to keep them in place longitudinally, and, as each joint occurs at a yoke, the washer of the tie-bar, which bears half on one rail and half upon the next rail, keeps the two rail-ends in line horizontally. These slot-rails are 30 feet long.

The track-rails are of the ordinary vignole type, 7 inches deep, 102 lbs. per yard in weight, with 7 inches wide bottom flange and $1\frac{1}{16}$ inch wide groove. The groove is widened to $1\frac{3}{16}$ inch at sharp curves. They are rolled in 45-feet lengths, and are strongly jointed together by double fish-plates and an "anchor" plate under the bottom flange 24 inches long and riveted with six rivets to this flange.

14. Inspection chambers, 15 feet apart, are built in at each conductor-rail insulator. Fig. 93 shows the cover of one of these chambers, formed of a cast-iron box paved with granite-setts. At mean spacings of 180 feet these chambers are enlarged and connected by drain-pipes to specially built sumps and thence to the sewers. The distance between such drainage connections varies from 120 to 240 feet. At places where the conduit is made shallower in passing over bridges, or in order to avoid disturbing large pipes lying near the surface, drainage must be provided at closer intervals. In level

stretches a heavy downfall of rain is apt to flood the conduit, when, if the water reaches the level of the conductor-bars, the section is short-circuited and must be cut out, thus rendering tram traffic along it temporarily impossible. In London a great deal of liquid mud enters through the slot, so that in the worst places the conduit has to be cleaned out daily. In the discussion on Mr. Millar's paper on these South London tramways before the Institute of Civil Engineers, in January, 1904 (see Proc. vol. 156), Mr. Rider complained that "the borough authorities with their mechanical sweepers and men sweepers, swept all their mud into the conduit." A scraper of the approximate size and shape of the conduit is used to clean it of mud, and a steep gradient of, say, 1 in 6 is needed in the drainage pipe down to the sump provided to catch it to induce this mud so scraped along to a drainage opening to flow away by gravity.

15. Figs. 94, 95, 96 give a side view and two sections of the plough used on these lines, designed by Mr. Connett, and very similar to those previously used in America. For this and several other illustrations of the South London conduit trams the author is indebted to the Institute of Civil Engineers, and to Mr. Millar mentioned above. The collector wing-skates are $7\frac{1}{2}$ inches long, with a curved bevel on each end, leaving 6 inches length of bearing surface. The two are opposite each other, and are supported vertically each by two hinged arms with vertical hinge-pins on the body of the plough. They are pressed outwards laterally by light plate springs. The current passes to them by flexible leads well covered with insulation. These leads are connected to 3-inch wide thin copper strips running down the centre of the plough, the one strip being in front of the other with a space of 7 inches between them. These strips are covered with insulating material; and, outside this, two stout sheet-steel guard-plates make up a thickness of $\frac{5}{8}$-inch in the part which runs through the $\frac{3}{4}$-inch slot. The lower part is stiffened with plates of wood, steeped in, and thickly painted over with, an insulating composition impervious to wet. This construction is said to have given trouble in wear and tearing of the guard-plates and destruction of the insulation, so that each car has to be provided with two ploughs, one being in the repairing shop while the other is in use. It is understood that improved patterns are being gradually developed experimentally. The plough is slung under the car-truck in a manner which gives it free lateral play, but vertically it follows all the oscillations of the underframe of the truck. The guide-bars which permit the lateral play are open at their ends, so that, if at a junction facing-point the plough enters the wrong slot, it is simply pushed off its support on the car-truck and falls detached on the line.

16. Points and crossings in a conduit tramway are naturally much more complicated and expensive in construction than in any

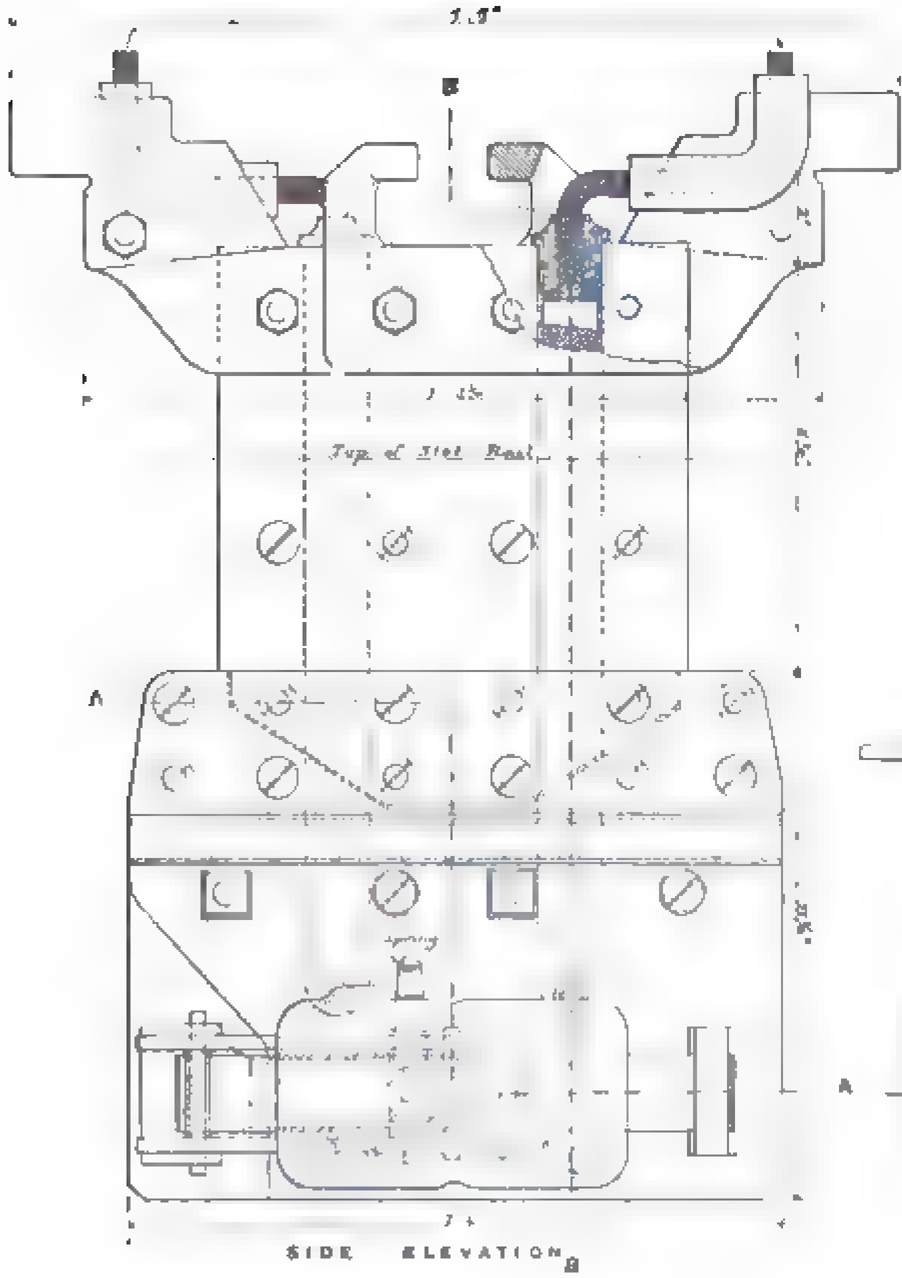


Fig. 94.

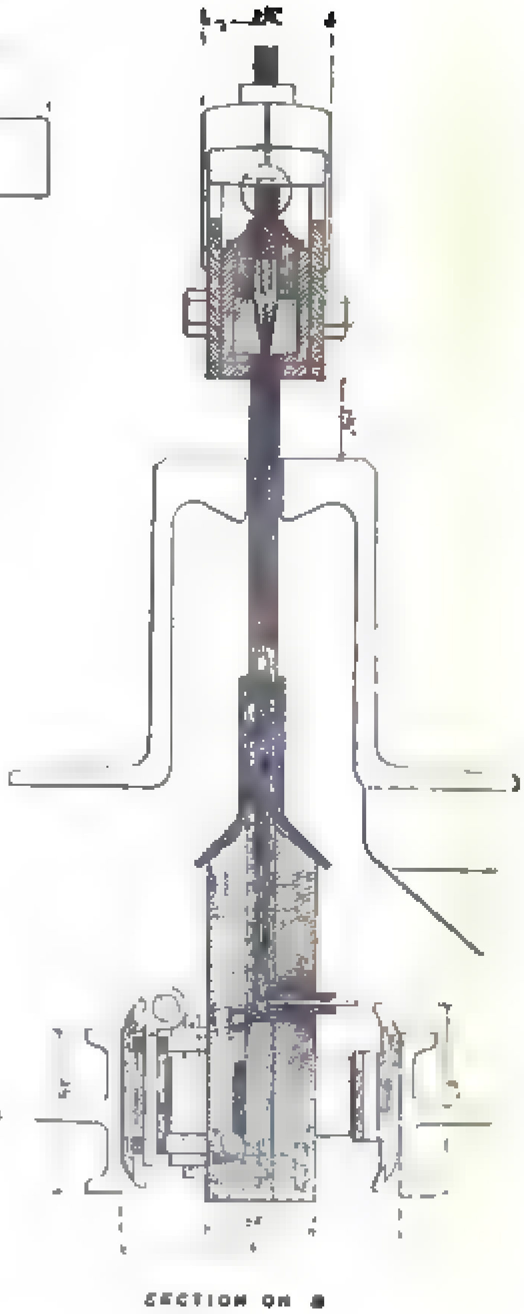


Fig. 95.

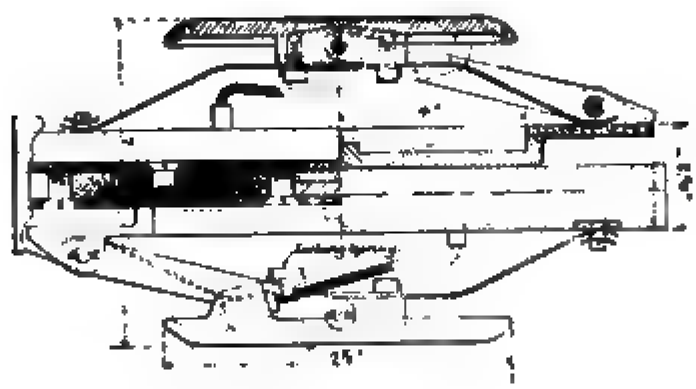
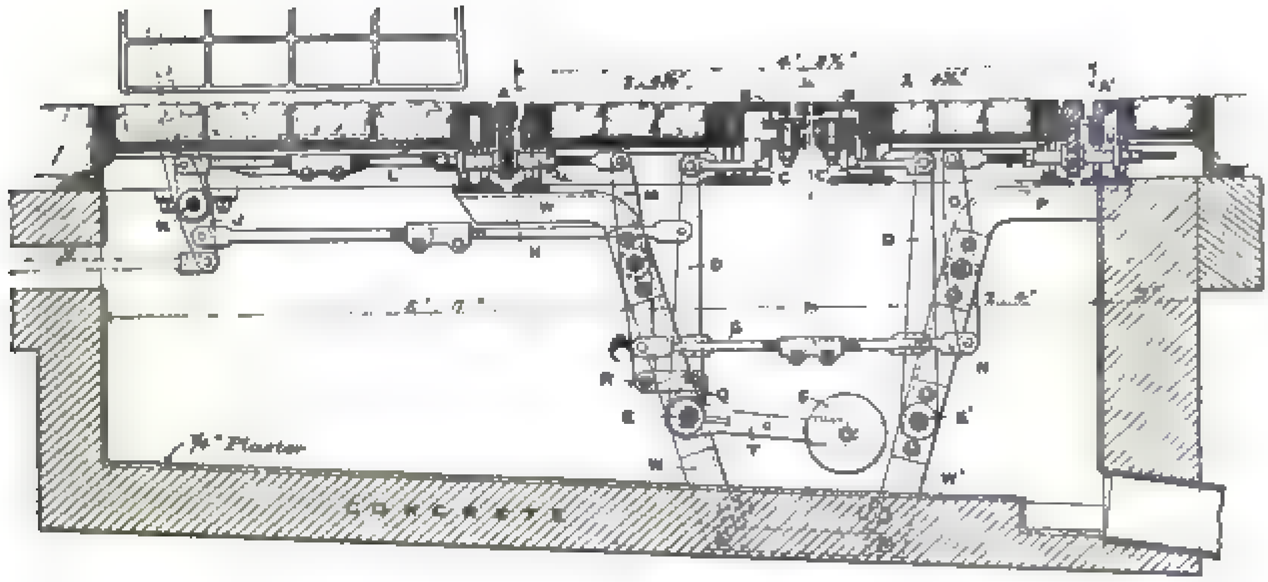


Fig. 96.

other form. Fig. 97 is a view of the mechanism at a facing-point. It is not attempted to switch the conductor-rails: simple breaks and gaps are left in these. There remain four rails, namely two track-rails and two slot-rails, to switch. The gaps in the conductor-rails are on the average 12 feet long. This results from the two rails on the inside of the point being of opposite polarity. They approach each other at a very acute angle, and cannot be allowed to come within 3 inches of each other. Thus the gap-length depends on the angle at the junction. As far as possible this angle is kept the same throughout the tramway system, so as to avoid the use of various patterns of switch castings, etc. For the same reason it is endeavoured to avoid crossings except at a few standard angles.



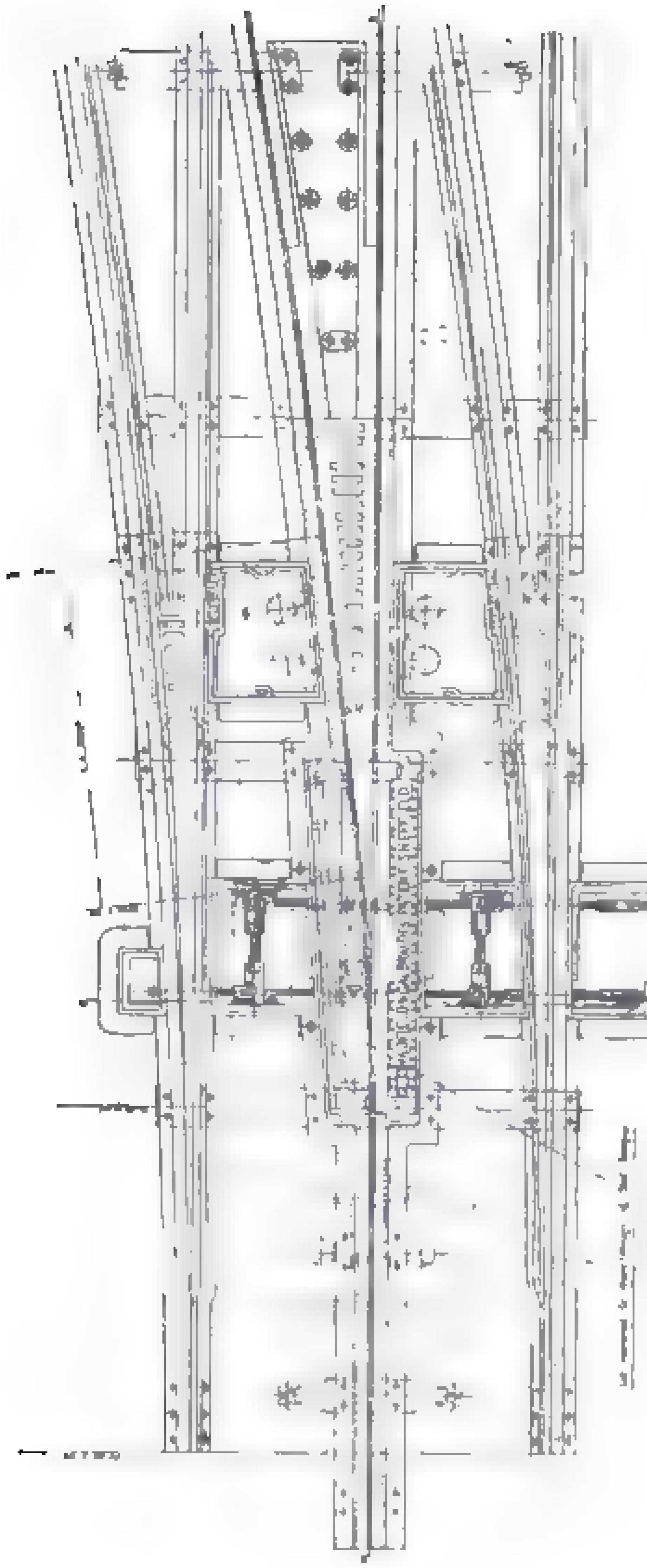
SECTION ON A A.
SWITCH MECHANISM AT JUNCTION.

Fig. 97.

The unavoidable complexity of the points and crossings problem is easily realized. With track, slot, and conductor, each single line has six rails. The crossing of two single lines, therefore, involves 36 rail-intersections in place. The crossing of double-track lines involves $4 \times 36 = 144$ rail-intersections. Dealing with the conductors by simply cutting them and leaving gaps, there remain on the surface 16 intersections in the one case, and 64 in the other.

At an acute-angled junction of two single tracks, there occur on the surface four rail-facing-points, namely two of track-rails and two of slot-rails; and five rail-intersections, namely one of two track-rails, two of one track-rail with a pair of slot-rails, and two more of the other track-rail with the other pair of slot-rails.

At a similar junction of two double-track lines there are on the surface double the above list of points and crossings, plus 16 other



Arrangement of Track and Slot Points

Fig. 98.

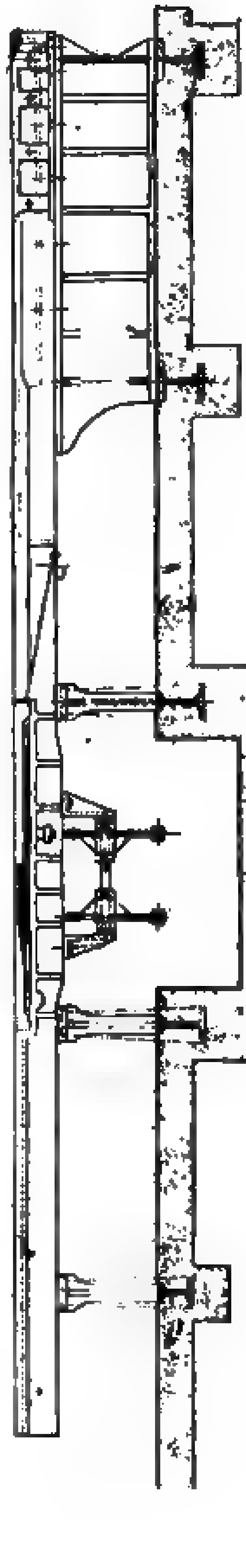


Fig. 99.

crossings, or 8 points and 21 crossings in all. Besides these, if the conductor-rails were carried through, there would be underground 4 other points and 4 other crossings.

The points and crossings of the track-rails are in no essential different from those on ordinary railways and tramways.

17. The latest design of slot-rail points is a much improved one, used for the first time on the Kennington to Streatham line. It is the invention of Mr. Galbraith, of Messrs. Hadley's Steel Foundry Co., and is supplied by this firm. Figs. 98, 99, and 100 show plan, longitudinal section, and cross section of a junction on this design. All the surface iron plates are ribbed to give foothold to horses passing over the junction. In previous designs the two

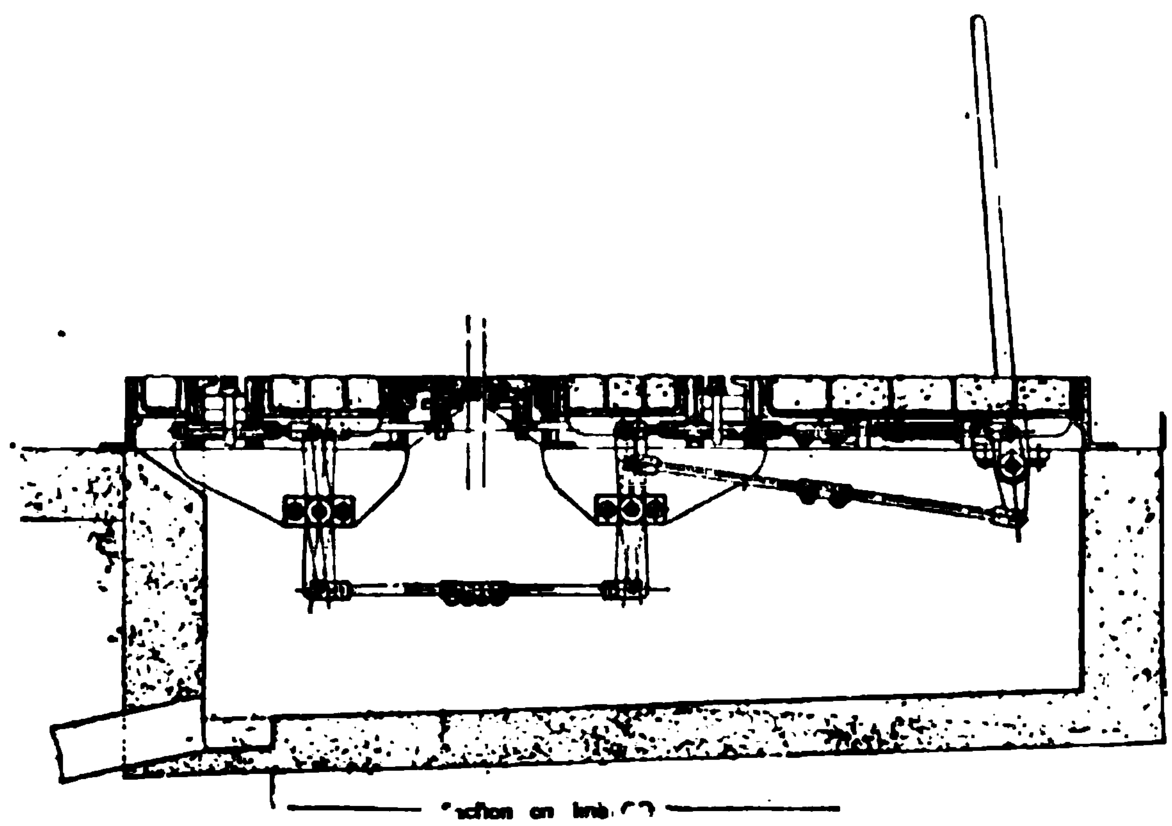


FIG. 100.

movable facing-points of the pair of slot-rails had a portion of their areas coming to the surface, which portions had to be ribbed by casting rectangular tooth-shaped projections upon them. In moving laterally with the shifting of the points, these teeth necessarily left at one side or the other of the slot a longitudinal gap which was not only dangerous to cycles, but also allowed mud, stones, and dirt to fall into it, hindering or preventing wholly the subsequent shifting of the points. In the new design no part of the moving tongue comes to the surface. The pair of tongues are covered by three fixed plates or lids, whose edges form the sides of the two divergent slots and their common junction. Beyond the point these fixed edges are, of course, incapable of guiding the plough into either of the two ways, the width between them being about three times the width of a slot, or $2\frac{1}{4}$ inches. The under side of each covering plate is ribbed transversely, these ribs giving strength to the plate at its weakest

part to carry the traffic passing over it. The upper surface of the point-tongue, which moves under the cover-plate, is similarly ribbed, its ribs fitting between those of the cover. These tongue-ribs reach to within ½ inch of the surface. Over them the cover-plate is only ½ inch thick, but its numerous ribs give it ample beam strength. Below the tongue-ribs the tongue-plate has ¾ inch thickness, and its continuous edge of this thickness forms the main guide for the plough. Coincident in plan with this guiding edge there is, however, a broken guide-face formed by the vertical ends of the tongue-ribs. The ribs being 1 inch deep, the total depth of the guiding face is 1¾ inch, which is more than the depth in the ordinary slot-rails, and gives ample wearing surface. The arrangement does not allow of the intrusion of dirt into the joints. What dirt falls between the ribs of the tongue is scraped off and thrown into the conduit chamber below as soon as the point is shifted.

18. These last drawings illustrate the need of providing, at great expense, much heavy underground girder work in the large open chambers under the junctions and crossings. In especial is to be noted the massive longitudinal girder supporting the point between the two divergent conduits. This point, which itself is a massive steel casting, overhangs the extremity of the girder by no less than 3½ feet, and in the older designs by 5½ feet.

19. The feeders to the line, which, of course, are in each connection duplicated because of the insulated return, are brought in from ½-mile section-boxes placed above ground on the side pavement and equipped with all the necessary switches and testing connections. In each section independently, the polarity of the two conductor-rails can be reversed by a switch at the sub-station. As a matter of system, the polarity in all the sections is reversed at more or less regular intervals. The main object of this "change-over" switch is to make it possible at any time to give negative polarity to any conductor in which a fault is found, so that if this fault cause leakage to earth such leakage will be on the return side of the circuit.

On the Kennington-Streatham line the feeders are laid on the "solid" system under the side pavement.

As an example of how the feeder system works out, the following dimensions of the feeders from the sub-station near the Streatham end to the five sections into which the Streatham line is divided may be given:—

Feeder No.	1	2	3	4	5
Copper section, square inch ...	0·50	0·25	0·10	0·10	0·30

The cable sections vary with the length of the cable, but still more with the density of the traffic they feed. All the cables are paper insulated and lead covered. The low-tension cables from the

sub-station are single-cored. Those for the high-tension transmission from the generating to the sub-stations are 3-core.

20. At present there are six sub-stations, namely those at New Cross, Elephant and Castle, Kennington, Camberwell, Clapham, and Streatham. The main generating station, not yet equipped with plant, is to be at Greenwich, and it is hoped that it will be ready to supply current early in the year 1906. The nearest sub-station to this, namely New Cross, is two miles distant, while Streatham, which is the furthest off, lies seven miles from the central station.

The length of line worked from one sub-station varies with traffic

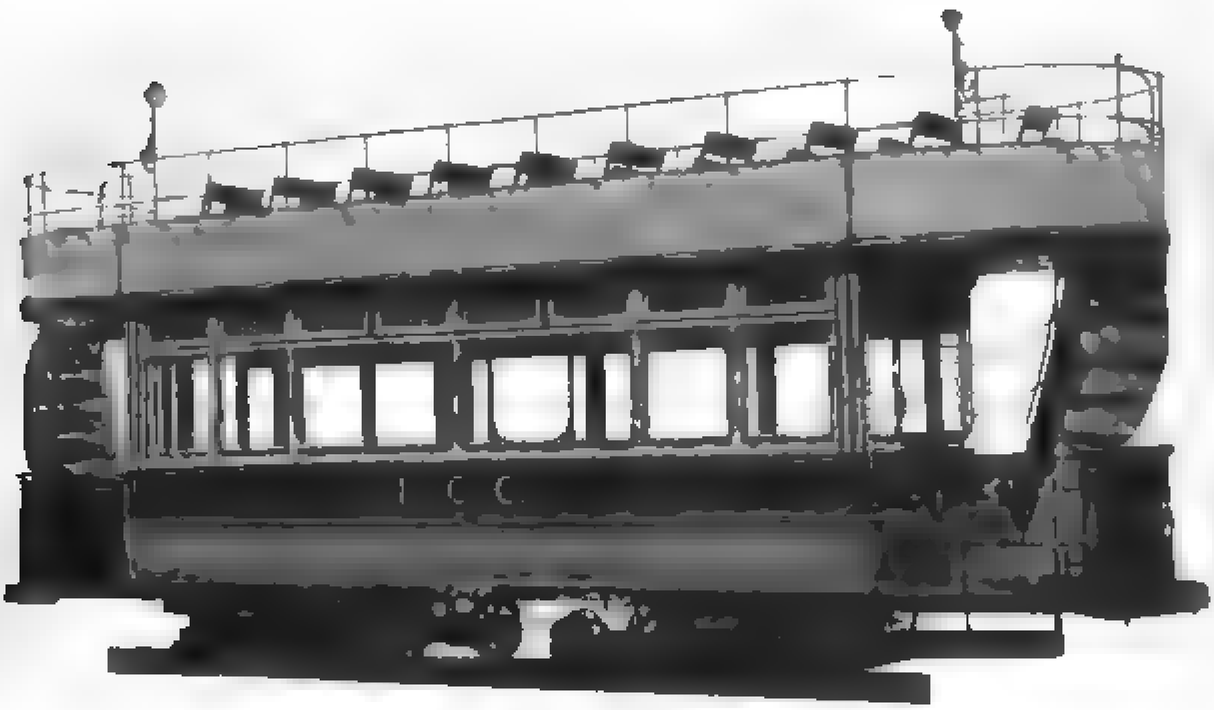


FIG. 101.—Exterior of London County Council Cars Double-deck, Two-bogie, Maximum truck, Conduit traction.

density, each sub-station being intended to supply about 150 cars in active service. The motor generators used in these vary in size from 300 to 500 kilowatt. From Camberwell sub-station about 3000 B.T. Units only of direct current energy at 550 volts are at present sent out from the bus-bars per day. A reading taken at 5 p.m. in summer time gave 420 ampères, which at 550 volts means 230 kilowatt. The mean kilowatt rate at this station is $\frac{3000}{24} = 125$. This is only a small proportion of what will be ultimately supplied from this station.

21. At the Greenwich central station the intention is to lay down 48 water-tube boilers, working at 200 lbs. to the square inch pressure.

These are to supply 8 surface condensing engines, each of a normal horse-power of 6500, at 94 revolutions per minute; or 52,000 horse-power in all. There are to be 8 three-phase dynamos, each generating 3750 kilowatt, or 5000 horse-power, at a frequency of 25 per second, and 6600 volts in each phase-difference; the total electric capacity being thus 40,000 horse-power, or 77 per cent. of the engine indicated horse-power. There will be one exciter to each dynamo, and the intention is that it shall be rope-driven. All auxiliary plant is to

Fig. 102.—Interior of London County Council Cars.

be motor-driven. Oil switches will be used for all high-tension control, and these will be operated electrically from a distance by low-tension relay apparatus.

This station is situate on the south bank of the Thames, and coal will be supplied to it by water, condensing water being also taken from the river. It is intended to supply energy to tramways north as well as south of the Thames. It is being laid out under the superintendence and direction of Mr. J. Rider.

Another generating station is projected, and a site for it has been purchased at the price of £80,000 in the Pimlico district, also close to the river, with water-wharfage; but this is not likely to be required for the next few years.

22. Meantime power is being supplied from a temporary station at Loughborough Junction. Here the plant of engines and generators, etc., is owned by the London County Council and is run by their servants; but steam is supplied to it from the boilers of the South London Electric Supply Corporation. The price paid by the Council for the steam is 1·4 penny per B.T. Unit of electric energy generated. This is an excessive price to pay under the just mentioned circumstances, which must greatly obstruct efforts after economical financial management. The arrangement is also obviously one that does not encourage efficiency in the engine consumption of steam.

23. The cars on the South London lines have double-deck bodies on maximum traction bogie trucks, with one 35 horse-power motor on each truck. They are seated for 28 inside and 38 outside passengers, and are well lighted. They have illuminated destination placards at each end, and no advertisement decoration is allowed. The top deck has been uncovered, but at present many of the cars are being fitted with an upper-deck roof, experiments in this direction having gained public approval and the bridges on most of the lines offering no insurmountable obstacle to this addition.

Figs. 101 and 102 give photographic views of the exterior and interior of these cars, which are built by Dick, Kerr & Co.

24. The London County Council is now completing an extremely important shallow subway tram-line under the new street to be called the King's Way. This stretches from Vernon Place, in Southampton Row, just north of High Holborn, to the Victoria Embankment on the north shore of the Thames under Waterloo Bridge. This has been an expensive undertaking on account of the very large amount of demolition involved of house property in the heart of the City. This demolition has not been necessitated for the construction of the tram-subway, and its cost is not to be debited against this form of city tramway. The scheme was primarily undertaken with two objects: (1) to provide a very much-needed wide street connecting Holborn and the Strand; and (2) in order to clear out a great quantity of insanitary and otherwise undesirable rookeries of great age and to a large extent dilapidated. The new street on the surface is 100 feet wide, 60 feet of carriage-way, and 20 feet of pavement on either side. The primary object being to deal with congestion of traffic, it was decided to build a subway along the route for two lines of trams. Buda-Pesth was again the leader in the adoption of this most modern plan of city locomotion, and the shallow subway there has proved one of the

pleasantest and most useful of methods of rapid transit. New York, Paris, and Berlin have followed very successfully the example of Pesth, and London is now making her first experiment in this direction.

The work is also most important in another way. It is the first tramway that has been permitted through the densely busy part of London; it forms the first tramway link between the Thames and the northern part of the City. It is hoped soon to break down the persistent opposition that has hitherto defeated the proposals to bring the tramways across the bridges and along the Embankment. When this first line from the north and debouching on the Embankment is finished and its utility has been demonstrated, it will be found impossible any longer to obstruct the completion of the network between north and south. From the point of view of tramway development in London, this is the most important aspect of the King's Way undertaking.

25. Fig. 103 is a longitudinal section of this subway, and Figs. 104 and 105 are cross-sections of the shallow and of the deep-level portions of it, these sections having been kindly supplied to the author by Mr. Maurice Fitzmaurice, Chief Engineer to the London County Council.

Starting from the north end at Vernon Place, the two tram-lines descend from the street level by a sharp incline of 1 in 10 gradient and 345 feet length, the first 170 feet being in the open. The next 75 feet is covered masonry work, and this is succeeded by 250 feet length of duplex tube-tunnel of similar design to that described at length later in this book in connection with the deep-level railways of London. The first steep incline is followed by 200 feet of 1 in 200 down-grade, and this again by 120 feet of steep 1 in 10 up-grade. This dip is necessary to take the subway under High Holborn and under the large sewers and other pipes that run east and west along the line of Holborn. The rails are here 31 feet below the road surface in Holborn. At Gate Street, at the end of the 1 in 10 up-grade, the depth below the surface in King's Way is 17 feet, and this depth is maintained until the dip to pass under the Strand is reached. The down gradient along the King's Way is 1 in 105. The dip under the Strand is commenced at the north end of Aldwych, the great new Crescent on the Strand, which is one of the fine features of the above-mentioned clearance of slum property. The dip is at 1 in 20 gradient through 490 feet length, and 1 in 108 through 210 feet length in passing under the Strand. An almost level stretch of 450 feet brings the tramway to the Embankment at the same level as the roadway. From this terminus stairs lead up to the higher level of Lancaster Place and Waterloo Bridge. In passing under the Strand the rails are 34 feet below the road surface. The total length is a little over 3500 feet. In plan the line is straight as far as Aldwych Crescent, and then turns to follow the western sweep of this Crescent.

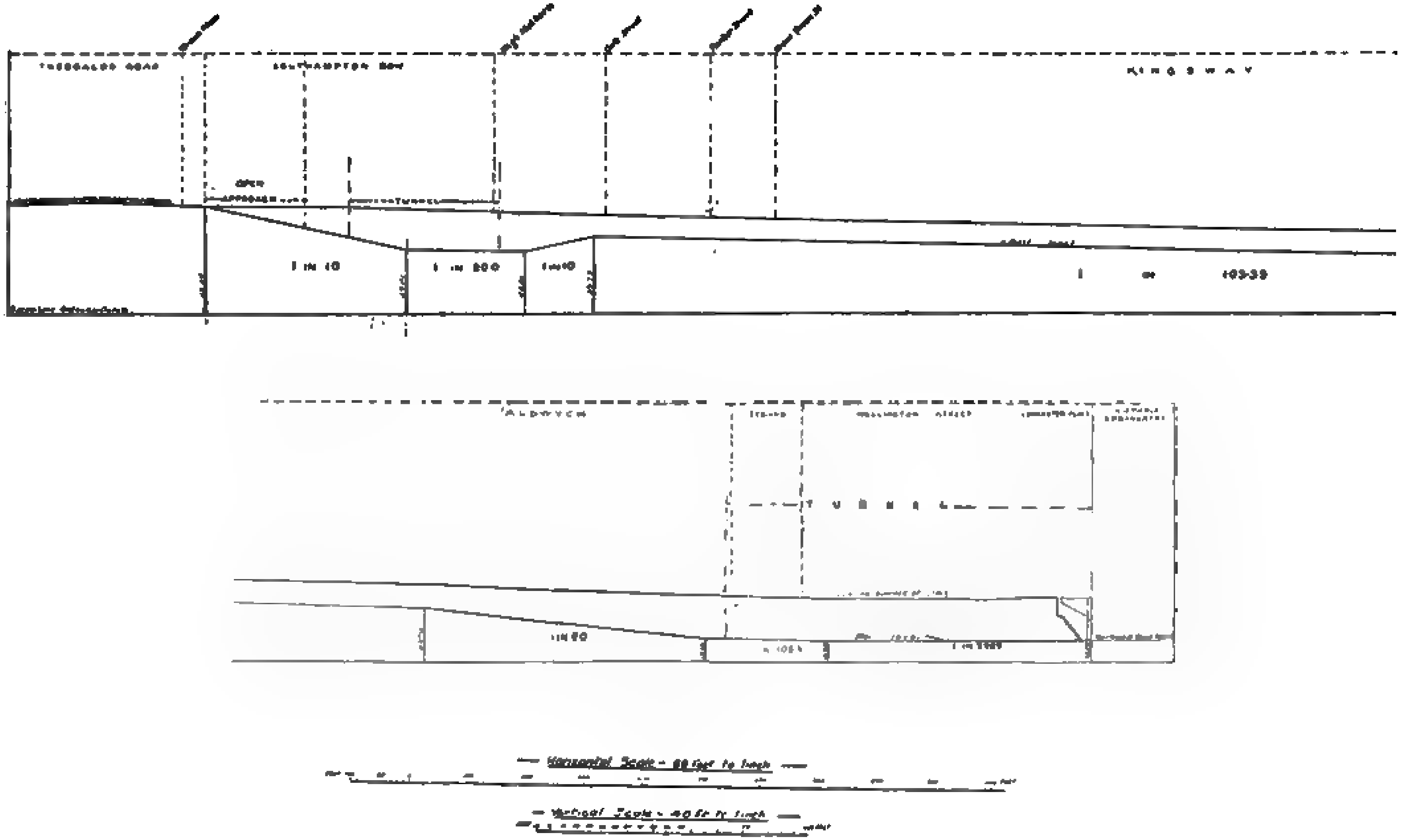

THEOBALDS ROAD
SOUTHAMPTON ROW
KINGSWAY
OPEN APPROACH
1 IN 10
1 IN 200
ALDWYCH
T U N N E L

FIG 103.

At intervals, as marked on the section, are built underground station platforms. Access to each of these is obtained by a wide and easy staircase, descending from an "island" pavement in the middle of the King's Way. Underground entrances from the side pavements are unfortunately impossible, because of the pipe-subways seen in the cross-sections, Figs. 104 and 105.

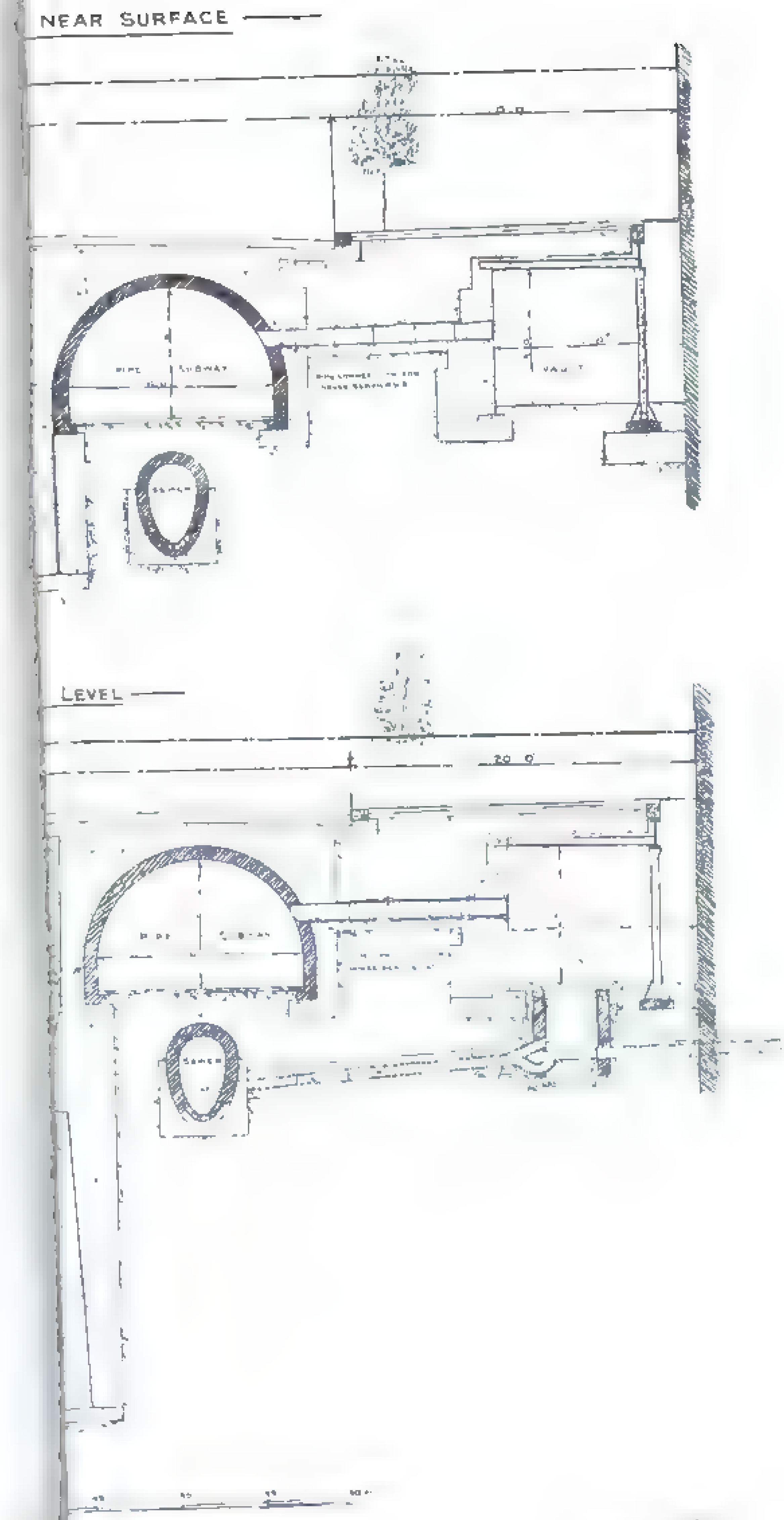
26. Fig. 104 shows the construction in the shallow lengths. The subway is 20 feet wide by 13 feet deep. The walls are throughout faced with white glazed tiles. The floor and foundation bed are of concrete, 4 feet 3 inches thick, with two layers of asphalte laid in it, as shown by the thick black lines. The concrete walls are 5 feet thick in their lower part and 3 feet 6 inches in their upper halves, alongside of which are built two semicircular arched subways for pipes. These are each 12 feet wide by 7 feet 6 inches deep, and under each is laid a new sewer of large size. The roof of the subway is made of trough-girders. This troughing is 12 inches deep, of 32-inch pitch, and of ½-inch thick steel plate. On the top of each wall is a heavy coping of York stone, and on this are bedded the ends of the trough-girders in cement concrete with two thicknesses of tarred roofing-felt interposed. The troughs are filled up with concrete to a small depth above the metal, and over this are laid two successive layers of asphalte, each about 1 inch thick. Over this is laid a bed of concrete and the road surface in asphalte. The depth from the bottom of the troughs to the crown of the road surface is about 3 feet 6 inches, making, with the 13-feet depth of the subway, about 16½ feet from rails to roadway.

Where the depth below road surface is greater, a brick arch roof is substituted for the flat trough structure, the former being very much cheaper. This section is shown in Fig. 105. The height from rail to the intrados of the arch is 14 feet.

In passing under Holborn and under the Strand, the subway splits into two circular tube-ways, each 14 feet 10 inches internal diameter. These were driven with a Greathead shield by hand excavation, and are lined with heavy cast-iron "segments."

27. In the stations the subway is increased to 30 feet in width, with 14 feet 9 inches depth to the under side of the roof. The station is partially lighted from the roof to the extent of the overhead "island," and it also receives some daylight from the staircase, which is wide and of small depth. It will also be well lighted electrically. The station platform is placed between the up and down lines.

Two lines of conduit trams are laid along the subway. The exact pattern of conduit is not yet finally determined upon; but it will probably be the same as that described above for the Kennington-Streatham lines, with only non-essential detail modifications.



[To face p. 166

CHAPTER VI

SURFACE-CONTACT TRAMWAYS

1. THE disadvantages, from the public point of view, of the two kinds of tramway already described are very obvious. On the one hand, overhead wires along and across the streets and high poles ranged down either side of them are undeniably unsightly and dangerous, especially when superadded to the existing encumbrance of telegraph and telephone wires and lighting lamp-posts. On the other hand, a slot in the surface is also objectionable and the expense of building a large underground conduit is great. These objections are so self-evident that it is hardly an exaggeration to say that almost every engineer of any degree of intelligent enterprise, who has been engaged in connection with tramway work, has spent some time and effort in trying to discover some means of bringing the electric energy to the car without exposed conductors. The reasons against carrying the energy on the cars in secondary batteries have already been explained

in Chapter I. This mode of propulsion has been given long trials, which have proved failures; and, although the system might still be made practicable by the perfecting of the batteries and their suspension, it has already been proved inferior to either overhead or conduit constructions.

2. Since the earthed track-rails may always be used as the return, the problem has usually been narrowed to that of temporarily connecting each part of a buried and insulated out-conductor with each car as the car passes over this part.

3. A connection capable of transmission of energy is not necessarily a conductive connection; it may be inductive. It therefore does not necessarily involve actual material touch or close contact. All static transformers transmit energy by pure induction. Indeed, the *working* action of all dynamos and motors, whether continuous current or polyphase, synchronous or asynchronous, is strictly *inductive*, and the *conductive* connections are only made to lead the currents into and out of the working parts. It is, therefore, not surprising that many efforts have been made by scientific engineers to devise a system of tram-car propulsion by pure induction without conductive connection between the buried insulated conductor and any part of the car. In an induction motor, the energy passes from the stator to the rotor without making use of any material contact between the two. If the whole length of the tram-track could be constructed after the pattern of the stator, and the acting part of the car constructed as a segment of a rotor, then three-phase or other polyphase current sent through the track could be made to propel the car along the rails without conductive contact between the two, and without the passage of the track current through the car motor. If one thinks of a re-entrant track-circuit, and a continuous train of motor-cars covering the whole of this circuit, the strict analogy to an induction motor becomes complete; and then it is to be noted that discontinuity in the rotor part of the arrangement does not need to interfere with its working. It may also be noted that the working propulsive force does not need to be that exerted between the pole-faces of stator and rotor; just as the secondary current in a static transformer may do its work in driving a motor at a distance from the transformer.

In this system it is evident that a portion of the car, in which the secondary currents are induced, must make with the portion of the track over which it stands a complete and efficient magnetic circuit. The track must therefore be built suitably; that is, it must have in its construction along its whole length a properly disposed mass of iron of good magnetic permeability.

The weight and cost of the transformer and motor to be carried by the car on this plan would be considerable; but those of the copper

and of the high permeability iron in the track would be so enormous as to make it extremely improbable that the system can ever be turned to practical use. Nevertheless, the requisite quantities of material and of current energy have been worked out theoretically by Professor John Perry, by Mr. M. D. Korda, and by Messrs. Rosenfeld and Zelenay. The extravagant quantity of expensive material needed in the track arises from the large value of the "ampère-turns" required round the numerous inductor cores spaced closely along the road, and also from the badness of the magnetic circuit made between the road and the car. Although by employing rolling pole-pieces actual iron contact may be obtained, still the area of such contact is very small, and the virtual mean air-gap length must be very large. Again, the working efficiency must be very low because of the heavy copper and iron losses all along the route. These could only be reduced within possible limits by all the induction coils on the route being cut out of circuit, except when a car is actually passing over them. The automatic device for throwing each into circuit as a car approaches it is quite possible, but its introduction deprives the system of any superior theoretical advantage.

The name of "tangential traction" has been given to this system by its latest advocates, Messrs. Rosenfeld and Zelenay.

4. All the systems that have yet had any practical success have depended upon conductive contact between roadway and car, the main current along the buried insulated conductor being tapped and led through the car-motors and back to the earth-rails.

The return current through the running rails is all along its course, nearly at the same potential as the contiguous earth. No insulation is here attempted, and, if attempted, it would be found impracticable, owing to the great length of rail bonded together, the resistance between rail and earth being inversely proportional to the length. It is thus clear that another similar rail on the surface of the ground could not carry the out current, because the out and in conductors would be practically short circuited throughout their length. If, however, a surface rail be laid broken into isolated sections, and if the whole of this be disconnected from the buried supply-conductor except at the one section underneath a car to which power is to be supplied, then the resistance between this one isolated live section and the earthed return-rails will be greater in proportion to the shortness of the live section, and in proportion to the dryness of the road-bed surface. If the resistance through the car-motors be a great deal less than this, then the bulk of the current will pass through the motors and a comparatively small part of it through the earth from live section to return rail. If the isolating gap between the live section and the two neighbouring sections be

small, then there will also be leakage to these neighbouring sections, and thus to earth.

In the earliest attempts in this direction small gaps only were left between the isolated sections, and no attempt was made to insulate these from the general mass of the earth. The best known of such attempts was that of Lineff, on whose system a short length of tramway was worked in 1888 in Hammersmith in the west of London. Independently of the clumsiness and noisy character of his underground switch apparatus, which consisted in lifting by the influence of an electro-magnet carried on the car a long flat strip of iron laid in a diminutive underground tunnel, no reasonable efficiency could be obtained, on account of the heavy leakage to earth.

5. The first essential to success on these general lines is to diminish this earth leakage to a minimum. It cannot be reduced to zero, because a conducting surface has to be placed free and uncovered on the top of the road-bed. It is minimized by contracting the top-face dimensions of the exposed conducting surface to a round or square patch of a few inches size, and by embedding the metal stud, whose top face is thus exposed, in a block of good insulating material impervious to wet; also by elevating this exposed face to a slightly higher level than that of the road-bed, so that rain is shed away from it in every direction and cannot lie in a pool over it. The leakage to earth is now confined to the thin film of wet that may lie over the top surface of the insulating block in rainy weather, or of grease or mud in misty or foggy weather. The current is picked up from this stud by a long metal skate, and it is to be observed that the rubbing of the skates of successive cars over each stud keeps the tops of the studs clean even in bad weather and brightly polished in dry weather. Thus the earth leakage is reduced to that due to wet, grease, and mud lying on and around the peripheral outline of the stud-face defining its actual rubbing contact with the skate.

6. It seems evident that this earth leakage would be brought to its real minimum by arranging that the flat surface rubbed by the skate should extend a short distance beyond the metal contact face and over a margin or border area of the insulating block in which the metal is embedded. This insulating margin would then be kept dry by the rubbing passage of the skate. This may actually occur incidentally in some cases by reason of the gradual wear of the studs, but it does not seem to form part of the design of any system now in use. Possibly the reason is a fear that this plan would only transfer the line of leakage from the contact periphery of the stud to the momentary contact periphery of the skate. It appears, nevertheless, to the author to be the correct design for the top of the stud, and

quite wrong to leave exposed a large bevelled metal portion of the stud which is never touched by the skate, and which, therefore, the skate neither cleans nor dries.

7. This earth leakage can also be diminished by each car carrying fore and aft two rotary wire brushes made to clean a path along the line of the studs. This arrangement is sometimes seen in practice. The brushes should be driven at proper speed by chain-gear from the wheel-axles, and each brush should rotate in such direction as to throw the mud away from the car, its spindle being also set so as to throw the mud off to one side of the centre line. The path so brushed clean should be several inches wider than the contact-faces of the studs.

8. In all systems in use each stud is kept alive only while a car passes over it. Therefore, at each part of the line the leakage above referred to is only momentary; it lasts only the time occupied by the skate passing over the stud. Thus, if the skate were 20 feet long, and the car were running at 10 miles per hour, the contact would last 1·36 second. If the cars passed at 3-minute intervals, the contact at one stud would be maintained during $\frac{1·36}{180} = \frac{1}{132}$ only of the working day. If the studs be 10 feet apart, this intermittent contact is equivalent in effect to contact at a single stud being maintained permanently at spacings of 1320 feet along the track.[1] This is a legitimate way of looking at the problem of stud-to-earth leakage, and it enables one easily to realize why this leakage in stud tramways is not more serious than in overhead lines, and is less serious than in conduit lines. In these, earth leakage is going on constantly along every inch of line so long as the air is wet or damp. The more direct method of calculating the importance of the stud leakage is, however, to measure the leakage current while the contact lasts, and to find its ratio to the whole current passing through the car-motors and leak together. In taking this ratio, allowance must be made for the fact that during a portion of the time more than one stud—sometimes three—are alive under each car simultaneously.

9. Patterns of studs in actual use are illustrated below. They do not vary except in non-essential detail.

The studs are placed from 3 to 5 metres, or 10 to 15 feet, apart.

The skates in some systems are only a little longer than the stud spacing, so that they momentarily touch two studs, but touch only one during most of the time. In other systems their length is

[1] If each car were never in contact with more than one stud and were always in contact with one stud, the simpler calculation 10 miles per hour × 3 minutes = 880 × 3 = 2640 feet would be correct. The true calculation is, however, as above, namely, car speed × time interval between cars × spacing of studs ÷ length of skate.

rather more than two spacings, so that they are always in contact with two, and are momentarily in contact with three.

The contact-skates are hung on the under-frame of the car, and, as actually made on all existing systems, rub over the studs with a velocity equal to that of the travelling speed of the car. The abrasion is very considerable, and both the skates and the caps of the studs require rather frequent repair. If it were not for the difficulty of good insulation, the skates might be made of flexible metal belting stretched over pulleys of slightly less diameter than the driving wheels, and geared to rotate at the same speed as the driving-axles. The skates would then have a backward motion relatively to the car nearly equal to the car's forward motion along the rails, so that the rubbing of the skate over the studs would be forwards, but at a very low velocity, and the abrasion correspondingly diminished.

10. Each stud, as a car comes over it, has to be brought into conductive electric connection with the + main, and this connection has to be again broken as soon as the car has passed. This involves for each stud and for each car passage two movements of at least one switch. A series of switches may be combined into one controller, but at least one switch-contact per stud is necessary. If the studs be spaced at 10 feet, this involves the maintenance in good automatic working condition of at least 528 switches per mile.

The various patent systems of surface-stud tramway differ mainly in the design and arrangement of these numerous switches. They vary greatly in the degree of risk they offer of leaving studs alive behind the car, which occurs from the faulty functioning of the opening movement of the switch. Since, in a 3-minute service of cars, the number of such opening movements per mile of single track is $\frac{60}{3} \times 528 = 10{,}560$ per hour, or 158,400 per 15-hour day, the probability of such faulty functioning occurring occasionally is high; and since the danger to horses of leaving studs alive is very great, a very great amount of thought and ingenuity has been expended in devising forms of switch and modes of operating them which shall bring this risk down to a minimum.

11. The practically most important distinction between these various systems lies in the placing of the switches (1) immediately underneath the stud, and therefore in the centre-line of the tram-track, or (2) at the side of the road removed from the track.

A second important variation is that (*a*) in some systems the switches are placed singly and equally spaced along the route, while (*b*) in others they are brought together in groups arranged in switch-boxes. The systems belonging to class (1) must evidently all belong to (*a*); only those in class (2) can be differentiated into (*a*) and (*b*).

So far as concerns expense in copper connections between the supply-main through the switches to the studs, obviously class (1) is the least expensive, and therefore the most desirable. The main cables may be laid in a central trench, in which also are placed all the separate single-switch-boxes, directly on the tops of which boxes are built the stud-settings.

12. If the switches be removed to the side-walk at a distance B feet from the line of the studs, but are still placed singly at equal spacings apart, then, if N be the maximum number of cars on a half-mile section and b be the spacing apart of the studs, and assuming that a car may be fed at least temporarily through one stud only, the copper section of the main will be N times that of the branch from each switch to its stud; provided that the maximum current density in both be the same. Therefore the ratio of the weight of copper in the branches to that in the half-mile long main will be, on this assumption of equal current densities, $\frac{B}{bN}$.

Here, if N be the number of cars per single track, b is the actual spacing of the studs along this track. But if N be the cars on a double track, b must be taken half the actual spacing, and B the distance from the line of switch-boxes to the mid-line between the two tracks. Thus, if $B = 12\frac{1}{2}$ feet, $b = 10$ feet, and $N = 2\frac{1}{2}$ cars per half-mile of single track, the ratio is $\frac{12\frac{1}{2}}{10 \times 2\frac{1}{2}} = 50$ per cent. The extra cost would be greater than in this ratio, as the insulation of the smaller sizes costs more in proportion to their copper weight. For double track, taking $B = 17\frac{1}{2}$ feet, $b = 5$ feet, and $N = 5$, the ratio would be 0·70, the divisor remaining the same as for single track, but the numerator being increased in the ratio $17\frac{1}{2}$ to $12\frac{1}{2}$.

It should here be noted that this serious augmentation of the copper capital outlay is at once halved if it be arranged that each car should be always fed through at least two studs instead of one only.

It must also be remarked that, since the main cable has the current flowing continuously in it, while in the stud-branches the flow is only intermittent and momentary, the heating of these latter is very much lower in proportion to the magnitude of the current through them, so that they may properly have sections designed for a much higher current density. Also, the current density calculated for maximum economy on the principles explained in a previous chapter should be very much higher in the branches than in the main; in fact, about 10 or 11 times as much.

Thus with the car fed through two studs and, say, three times greater current density in the branches than in the section feeder-cables, the augmentation of copper spent in this system is reduced

for the two cases of single- and double-track installations from 50 and 70 to 8 and 12 per cent., while the increase of cost on cables and leads may be put at about 10 and 15 per cent. respectively.

This increase applies only to the half-mile sections, and not to the feeder-cables leading from the sub-stations to these sections. On these latter there is no increase involved.

13. If, now, the switches, instead of being equally distributed along the line, are grouped together as is now generally the case, this extra copper spent in the branches is considerably greater than the above. The object of this grouping is, firstly, to economize in switch-boxes and their building on the pavement below or above ground; and, secondly, to facilitate regular inspection and repair of the switches. If ten be collected into one box, the time spent in inspecting the ten is practically the same as would be spent in inspecting a single one isolated in its own box. The inspection is also a great deal more satisfactory, because, as any one car passes, the inspector sees the whole series of switches one after the other rapidly thrown over, and can judge much better of the regularity of the automatic action of the whole series than if he visited ten widely separated boxes and saw each switch act separately. In the latter case he could not inspect ten switches satisfactorily without waiting for at least ten cars to pass.

Here it may be pointed out in passing that, as regular systematic inspection is a most important feature of this system, in order to facilitate it and raise the probability of its being constantly efficient, the switch-boxes should not be put underground, but should be in the form of cast-iron pillars, standing above ground, with hinged doors giving—to the inspector furnished with the proper key—the easiest and quickest possible access.

If n switches be thus grouped together, the length of tramway served from one box will be nb for a single track and $\frac{1}{2}nb$ for a double track. The box is placed in the centre of this length, and therefore the average distance of a stud from its switch will be $(\frac{1}{4}nb + \text{B})$ for single track and $(\frac{1}{8}nb + \text{B})$ for double track. This has to be substituted for B in the last given formula. Thus, for equal current densities in the branches and in the feeder the ratio of increase of copper involved is—

$$\text{for Single Track} \qquad \frac{\frac{1}{4}nb + \text{B}}{\text{N}b} = \frac{n}{4\text{N}} + \frac{\text{B}}{\text{N}b}$$

$$\text{and for Double Track} \qquad \frac{\frac{1}{8}nb + \text{B}}{\text{N}b} = \frac{n}{8\text{N}} + \frac{\text{B}}{\text{N}b}$$

where in each case N here represents the maximum number of cars on one section of *single track* and is to be taken the same in both

cases. In each case the second term is the same as previously found for uniformly distributed (ungrouped) switches. The ratio of extra copper involved in the grouping is $\frac{n}{4N}$ and $\frac{n}{8N}$ in the two cases. Putting $N = 2\frac{1}{2}$ for a half-mile section, or 10 cars per mile of double track, the formulæ reduce to—

$$\text{Single Track} \qquad \frac{n}{10} + \frac{B}{2\frac{1}{2}b}$$

$$\text{Double Track} \qquad \frac{n}{20} + \frac{B}{2\frac{1}{2}b}$$

Putting B equal to $12\frac{1}{2}$ and a mean of $17\frac{1}{2}$ feet for single and double track respectively, these again reduce to—

$$\text{Single Track} \qquad \frac{n}{10} + \frac{5}{b}$$

$$\text{Double Track} \qquad \frac{n}{20} + \frac{7}{b}$$

14. The numerical results given below show that the first term represents a more serious increase than does the second, and that consequently double track is more favourable to this system than single track. The reason for this is that on double track the legal restrictions to half-mile sections means permission to do double work on double track within the same limits of space and through a single feeder-cable.

These ratios have to be halved if each car is constantly fed through two studs, and further reduced in the ratio in which higher current density is allowed in the stud-branches than in the feeder-cable.

The following two tables, XIII. and XIV., give these ratios for different values of b, the spacing between the studs, and of n, the number of studs fed from one group of switches in one box, on the assumptions that the car constantly receives current through two studs and that the current density in the branches from switch to stud is three times as great as in the feeder-cable. In each case the arithmetic result of the above formulæ is, therefore, divided by 6.

The tables also give the length of route served in each case from one switch-box. This length, which is nb, is tabulated under the name L, and the above ratio under the name R.

TABLE XIII.—SINGLE-TRACK SURFACE-STUD TRAMWAYS.
RATIO OF EXTRA COPPER IN STUD-BRANCH LEADS TO COPPER IN SECTION FEEDER-CABLE AND LENGTH OF ROUTE SERVED FROM ONE SWITCH-BOX.

Number of studs connected to one switch-box. n	Spacing of stud, b feet.	10	12½	15
10	Length served from one switch-box, L, feet	100	125	150
	Ratio of extra copper, R, per cent.	**25**	**23**	**22**
15	L, feet	150	187½	225
	R, per cent.	**33**	**32**	**30½**
20	L, feet	200	250	300
	R, per cent.	**42**	**40**	**39**

TABLE XIV.—DOUBLE-TRACK SURFACE-STUD TRAMWAYS.
RATIO OF EXTRA COPPER, R, AND LENGTH SERVED FROM ONE SWITCH-BOX, L.

n	Stud-spacing, b feet.	10	12½	15
10	L, feet	50	62½	75
	R, per cent.	**20**	**18**	**16**
15	L, feet	75	93¾	112½
	R, per cent.	**24**	**22**	**20**
20	L, feet	100	125	150
	R, per cent.	**28**	**26**	**24½**
30	L, feet	150	187½	225
	R, per cent.	**37**	**34½**	**33**
40	L, feet	200	250	300
	R, per cent.	**45**	**43**	**41**

These tables show in what degree copper economy must be sacrificed in order to obtain the undoubted advantage of replacing a

multitude of switch-boxes by a single box. They also show that although for a given number of studs grouped to one box the double track is more advantageously situated than the single track, still for a given length of route commanded from one box the expense is raised in greater ratio in the double-tracked than in the single-tracked route.

15. In the first system, in which the switches are laid along the centre-line of the track immediately underneath the studs, this extra copper expenditure on the branches is avoided. On the other hand, the switches are very inaccessible for inspection and repair; it is difficult, or impossible, to remove one for repair without stopping the traffic; and the mechanisms, which must either be heavy, clumsy, and expensive, or else light and delicate, are exposed to maximum liability to derangement from the shock and vibration of the traffic over them. The derangement of these switches, along with the resulting exposure of live studs to contact with horses' hoofs, is the one obstacle against surface-contact tramways being very largely used in towns. Their economy in consumption of energy is equal, and might be made superior, to that of overhead lines; the cost of repairs, except for these switches, is distinctly less than in any other kind of tramway; while the capital expenditure need not be very greatly in excess of that on overhead tracks, and is considerably less than on conduit installations.

16. The different patterns of contact tramway are also capable of classification by their modes of automatic operation of the switches. In some the switches have been closed and opened wholly by mechanical means. This method was exemplified in Waller and Manville's experiment at Northfleet in 1889, in which a sort of plough, or thin elongated and sharp-edged shuttle, was carried underneath the car, and, at each stud, split apart a pair of spring-closed contact-plates. When closed, the main supply current passed between these plates, but when open it passed by the shuttle through the car-motor. These spring-plates must lie in a groove if the track be on a public road. In any case the insulation cannot be made good, the plates remaining charged continuously all along the line.

In many systems the opening of the switch after the car has passed is operated wholly mechanically, usually by gravity and sometimes by springs. The closing of the switch when a car comes over its connected stud is invariably operated by electro-magnetic influence; sometimes by an electro-magnet carried by the car, more often by one placed in the switch-box. Sometimes the exciting current of the electro-magnet is the main supply current, sometimes a shunt of this, and very commonly both a shunt and the main current are employed electro-magnetically to move the mechanism. Again the electro-magnet may be excited by a battery carried on the

car. The original proposal to employ insulated rail-sections thrown into, and cut out of, contact with a main supply cable by a switch operated by an electro-magnet carried by the car was made in the patent of Professors Ayrton and Perry in 1882, so that in Britain since that date nothing but new special methods of carrying out this general idea can be subjects of valid patents.

17. Of the systems now in use, the simplest in idea is the Diatto. Experiments were made with this system in Turin and Paris in 1895 and 1897. It was installed in Tours, on the Loire, in 1898, the line running some distance south of the city and north of it across the river, and here joining on to an overhead track on which the same cars run up the northern bank to Vouvray. The writer has seen it working very satisfactorily in all weathers. Even when the track is covered with wet snow and slush there is no difficulty in

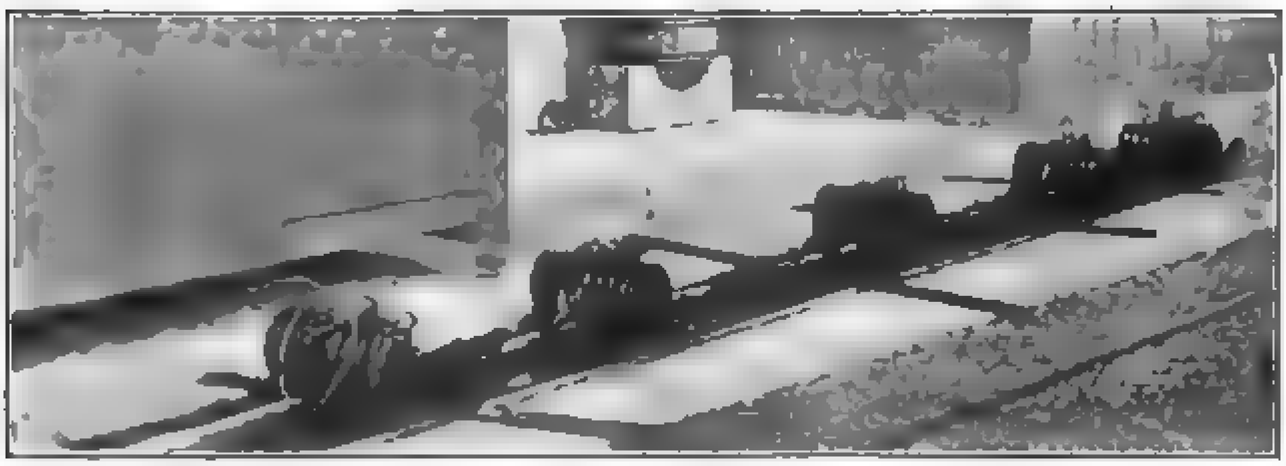


Fig. 106.—Skate and Magnets for Diatto Surface Studs.

maintaining regular traffic. Later it has been installed in Paris, both in the east and west of the city and on the left bank of the river. For this heavier traffic it has not proved successful, and many complaints have been made of its working.

In the Diatto tramways each switch is immediately below its stud, and is operated by five electro-magnets carried by the car. The contact skate forms one pole-piece of these magnets, the other pole being split or duplex, and being formed by two similar iron bars lying along either side of the contact skate but at a slightly higher level, so that they do not touch any part of the roadway. This combination of three long iron bars forming pole-pieces is shown in Fig. 106. In Fig. 107 is shown a section of the stud and the switch-box under it. The two magnetic circuits of the magnets shown in Fig. 106 are completed through the iron parts of this switch-box, namely through the central soft-iron plug F of the stud, the soft-iron pin O, the cast-iron cover-plate D, and the two wing-plates B, B,

which are of high-permeability charcoal iron. The two side-bar poles of the magnets lie immediately over the tips of the plates B, B. The iron of this circuit is magnetized each time a car passes the stud, remaining so so long as the three skates lie above it. It is demagnetized as soon as the skates have passed. The magnetic flux, so long as it lasts, lifts the iron pin O, which is floated in mercury

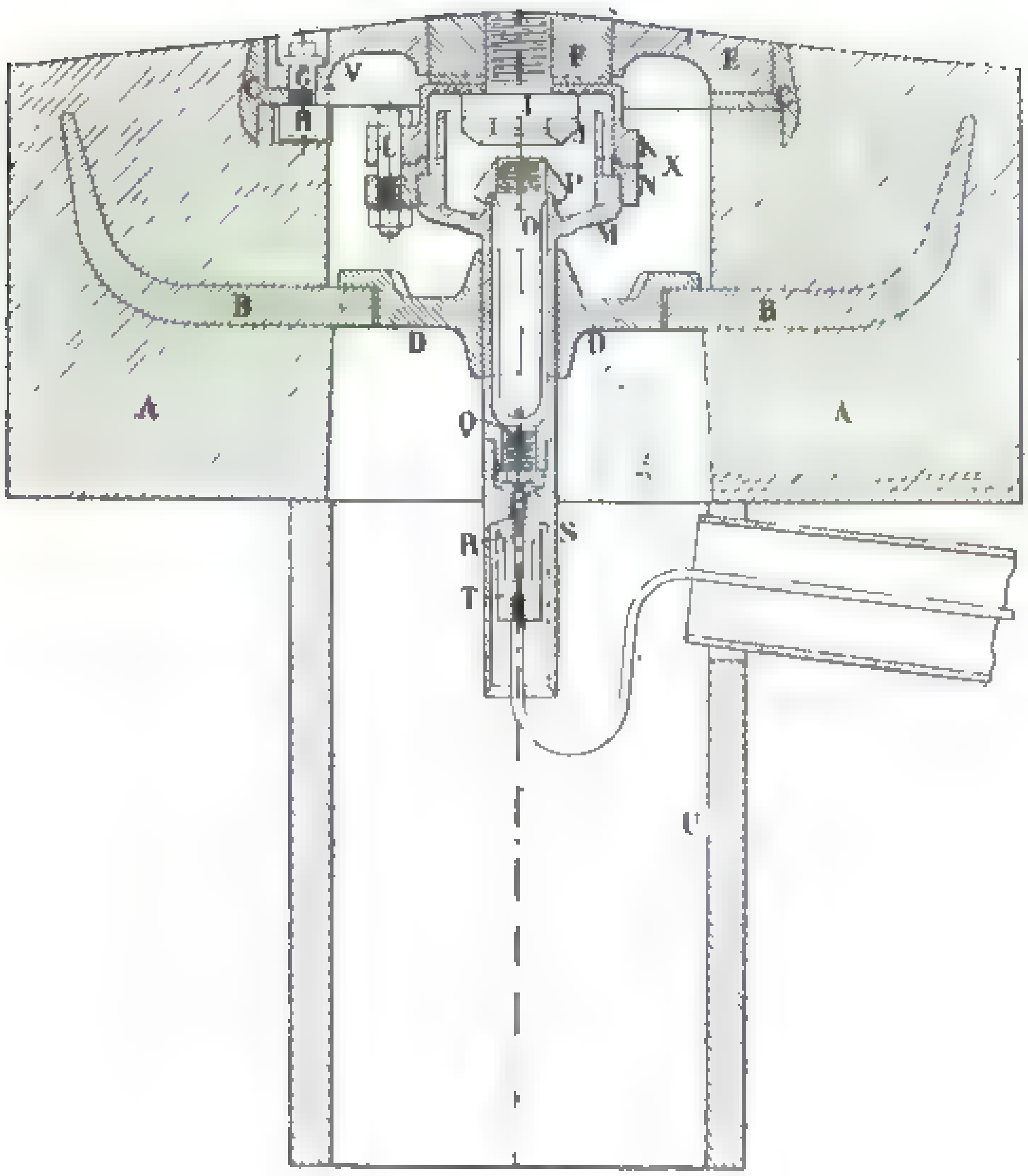


Fig. 107.—Diatto Surface Stud and Switch-box.

lying in the lower tube part of the ambroin cup M. The lift is about $\frac{3}{8}$ inch. On being raised the flotation, of course, decreases, and thus a portion of the weight of the pin is available to make it fall again as soon as the magnetic flux ceases. As soon as the car has passed, the only part capable of exerting magnetic force above O is the soft-iron plug F; and this being of small size, any residual magnetism

left in it is very feeble. The magnetizing current in starting is furnished by a small secondary battery on the car, and in running by a shunt off the main motor circuit. The battery is continuously in process of recharging except when the car is standing.

The pin O carries a conical head of hard brush carbon, P, and

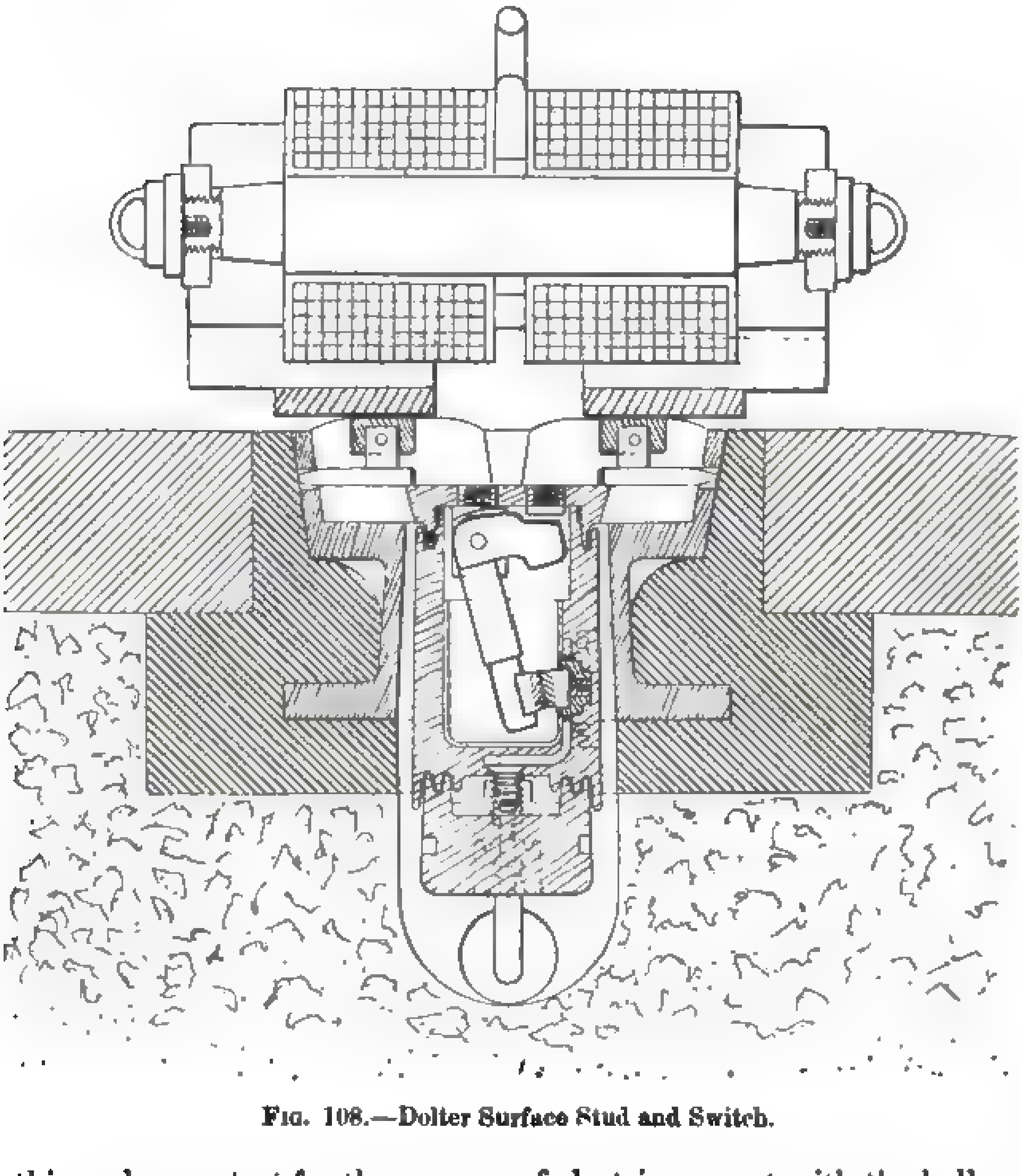


FIG. 108.—Dolter Surface Stud and Switch.

this makes contact for the passage of electric current with the hollow carbon cone J fixed to the plug F. The body of the pin O is of iron, but its lower part dipping into the mercury is covered with copper. Into the lower end of the cup M is screwed a copper stud, Q, the upper end of which is in contact with the mercury in M, and the lower end of which is prolonged as a small tail-pin, R, dipping into

another mercury cup, T. Into this cup is fixed the terminal of the branch from the main supply cable. The cup T, which is of insulating material, is covered by an ambroine tube, whose object is to prevent by the contained air the entrance of water if at any time the pit U containing the whole becomes flooded. The reason of the lower mercury-joint is to allow of the whole apparatus being lifted out for repair without breaking the terminal connection to the main cable. This could be accomplished more simply by a split spring plug. The whole construction is somewhat fanciful and needlessly complicated. For instance, the magnetic circuit would be as efficient if it were single instead of duplex, its splitting being apparently introduced for the sole purpose of maintaining geometric symmetry in the drawing, with the result of necessitating two side pole-bars instead of one, and making the electro-magnets double-ended with two bodies and two windings instead of one. The central plug F is set into a diamagnetic nickel-steel cover-plate, E, and this latter is screwed to a bronze ring, C. The ring C and the horn-plates B, B are laid into the asphaltic block A when this is moulded.

18. A very similar system is that patented by M. Dolter, and experimented on in the neighbourhood of the Bois de Boulogne, in Paris. The essential parts of this construction are shown in Fig. 108. The electro-magnets are transverse and horizontal, and are excited directly by a small battery on the car, which battery is charged by a shunt from the main current. Two longitudinal flat-iron bars constitute the two magnetic pole-pieces, and both of these bars act as current-collecting skates. The stud in the roadway has a square face, formed of two blocks of steel separated by a mid-rib of diamagnetic ferro-manganese. The magnetic circuit between these is closed by the lifting of a hinged soft-iron armature of small size, the free end of which is drawn upwards by the magnetic flux. This armature forms the horizontal arm of a bell-crank, whose vertical arm carries at its lower end a hard carbon block. This is one of the two contact pieces for the passage of the supply current to the car-motor, the hinge-pin of the bell-crank being in electric connection with the iron surface-blocks of the stud. The other carbon block is fixed in the side of the casing containing the whole switch apparatus. The movable carbon has a throw of nearly 1 inch, and the pressure between the two blocks when the switch is closed is said to be 20 lbs. The casing, or switch-box, is made in two parts, both of ambroin, the upper one of which can be lifted from above for repair of the apparatus, while the lower one receives the terminal of the branch from the main cable. The surfaces by which these parts fit one on the other have deep circular corrugations fashioned in them, and these are filled with vaseline to make a watertight joint.

The two surface-blocks of steel are embedded in a larger block of

ambroin, this being cast in and filling the conical upper part of a cast-iron entablature provided with a wide horizontal flange at its base. Round this entablature is moulded a large asphaltic block surrounding the bottom flange, and thus holding the whole very securely. The asphaltic block is bedded on concrete, and the street paving, whether of wood or of granite, covers its outer top edges.

In detail construction this design seems simpler, cheaper, and less liable to mechanical derangement than the Diatto design. Except for the friction at the hinge, there is perfect freedom of motion in the switch bell-crank. By substituting for the pin-hinge a spring suspension of thin band steel, the frictional resistance would be entirely eliminated.

19. In both the Diatto and the Dolter designs contact with one stud only is sufficient to obtain the supply of energy from the main. Along with this simplicity there is necessarily combined the disadvantage of dependence upon a battery carried on the car for starting the action. As the battery is small, and as a battery is very desirable to maintain the lighting of the car-lamps during stoppages, this ought not to be considered any serious disadvantage.

This dependence on contact with one stud only enables the studs to be spaced far apart. In both these systems the spacing has been made 5 metres on straight ranges. The skate is made a little longer, so that contact on each stud shall last until the switch of the next stud shall have been thrown over and the new contact securely established.

The ends of the skate are slightly bent upwards. This has two effects. Some bevelling at the ends is necessary, in order to prevent violent mechanical shock at each new contact with a stud. At the trailing end the mechanical and electric-current contact ceases before the magnetic flux is interrupted, because of this upward curved prolongation of the skate. Therefore the bell-crank is held up and the carbon blocks held together until after the current has ceased to flow. When the carbon blocks separate there is no current flowing through them, and therefore no break-flash. It is considered extremely important in all stud-tramway systems to avoid flashes inside the switch-boxes, as they are apt to destroy parts of the mechanisms. Their suppression is still more important when many switches are grouped together in one box.

In order to make sure that the carbon contact is broken and the stud discharged from high voltage immediately the car has passed, it is usual to add a short trailer-skate, which is connected to the car-frame and wheels and thence to the running rails and earth. If a stud be left alive, this trailer-skate makes a short circuit between the mains and earth, with the result of blowing a fuse which cuts out the whole section and prevents further traffic upon it until the faulty

switch is put right. The short circuit is led through a resistance which prevents the current rising to such magnitude as will do damage to the system generally beyond the blowing of the desired fuse. On the Diatto lines the trailer "safety" contact has generally

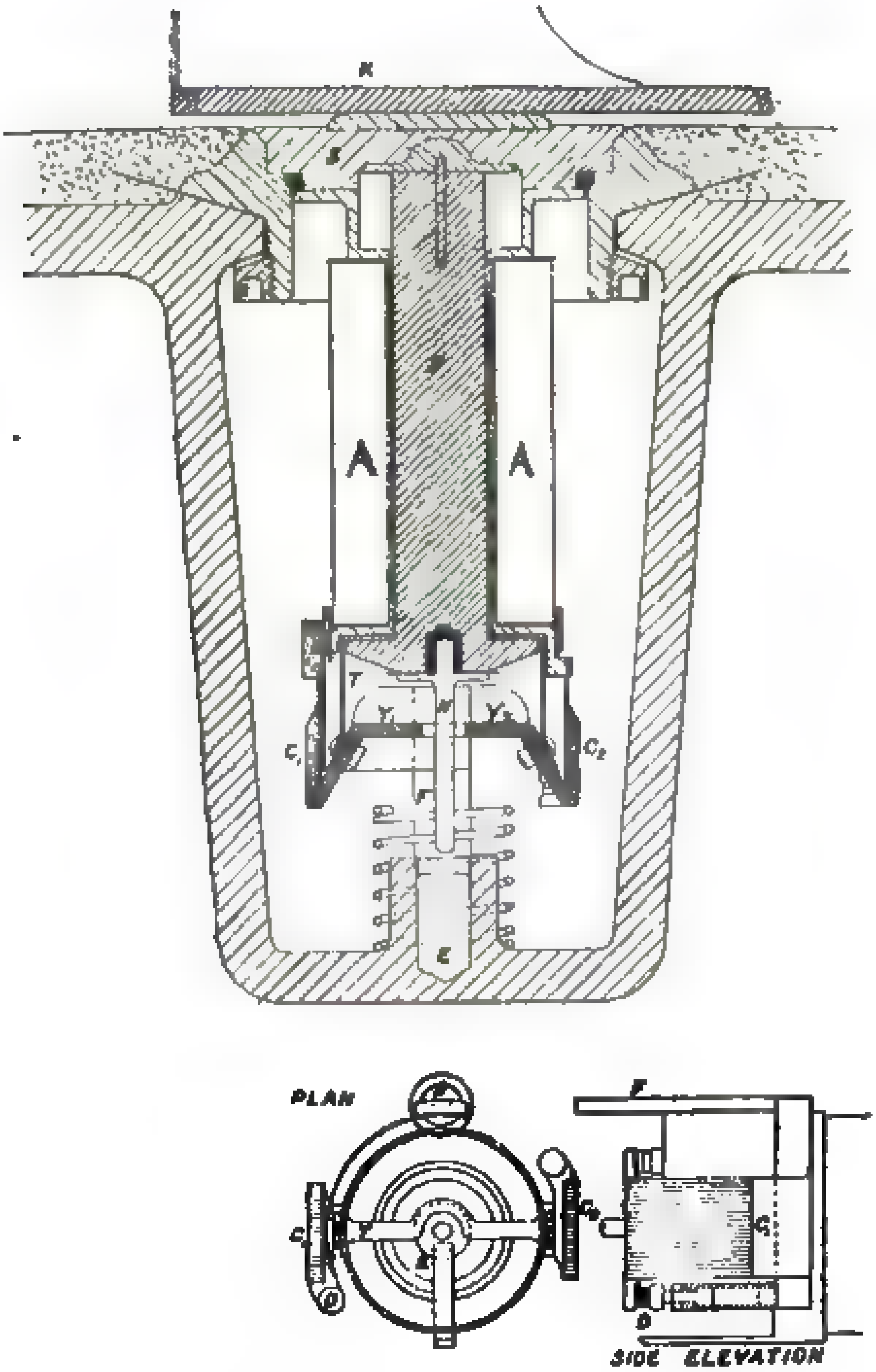


Fig. 109.—Thompson-Walker Stud and Switch.

been in the form of a short length of brass chain dragging loosely along the line of the studs.

20. In 1898 there was experimented on at Willesden, in the north of London, a surface-stud system invented by Dr. Sylvanus P. Thompson and Mr. Miles Walker, and in February, 1899, these

experiments were described by Mr. Walker in a paper before the Institute of Electrical Engineers. Fig. 109, borrowed from that paper, explains the construction and the principle of action. P is a soft-iron plunger of about 3 lbs. weight. It is surrounded by a solenoid, AA, which, when the stud is alive, forms a high-resistance shunt from stud to earth. The core or plunger P is provided with two expanded end-flanges or pole-pieces. The lower one is in one piece with the body, while the upper one is loose, the pin which projects from it and enters a hole in the body serving only to prevent lateral displacement. The solenoid attracts each of these end-pieces in such manner as just balances its central attraction upon the parallel body; when the whole is below mid-position, the attraction on the pair of heads is downwards, because of the top one being nearer, while the attraction on the body is upwards. Thus in the absence of other magnetic influence the solenoid exerts neither lifting nor downward pull of the core, so that, even if current continues to pass through the shunt after the car has passed over the stud, the solenoid does not interfere with the weight of the core causing it to fall. On the other hand, if any other piece of iron be brought near, above, or below the core, this not only disturbs the magnetic equilibrium top and bottom, but also strengthens the magnetic flux by increasing the permeability of the magnetic circuit. The iron collecting skate carried by the car has this effect, resulting in the lifting of the plunger P. It lifts with it a pair of copper contact brushes, Y_1, Y_2, making contact between C_1, C_2, and thus connecting the stud S to the supply main. The object of leaving the top pole-piece of the plunger loose is to eliminate its balancing effect throughout the lower half of the stroke, thus making the first half of the lift much quicker than it would be if the top head accompanied the body and the lower head through the whole stroke.

The skate is made some 3 feet longer than the spacing between the studs. The skate being charged from one stud, when it comes into touch with the next stud a shunt current from the skate through the stud and the solenoid to earth creates the solenoid magnetic field, which, with the help of the overhead presence of the iron skate, lifts the plunger and charges this stud. When the skate has passed away from over the stud, although the solenoid shunt current continues until the plunger has fallen and broken the contact YC, still this solenoid field has lost its power of floating the plunger, which therefore falls by its own weight.

Thus the switch YC is not opened until the skate is no longer touching the stud, so that the main supply current is broken between stud and skate, and not in the switch-box.

The plunger P moves the brushes through the intermediation of a thin brass tube, T, which fits easily round the core P throughout

the depth of the solenoid A, and which is expanded to larger diameter below A. In the lifting stroke the lower flange of P lifts the tube T. In the falling stroke P pulls the tube down by the viscous drag of the oil between them. The weight of the tube T and of the brushes Y attached to it also pull these down. Normally, the contact YC is broken as soon as the plunger has begun to move down. If, through sticking of the tube T in the outer tube which surrounds and guides it, the tube and the brushes fail to fall, then the small copper rod N screwed into the bottom of P descends into mercury placed in the cup E. The copper rod N has a wide flange at its upper end, and this, coming in contact with the brushes Y, produces a short circuit between the stud and earth through C and Y. The mercury is earthed because E is a hole drilled in a boss cast in the iron casing which contains the whole apparatus. The short circuit blows a fuse and cuts off all possible connection between the stud and the main supply.

The stud S is of gun-metal with an easily renewed facing-piece of phosphor bronze. It is screwed into a strong gun-metal ring, between which and the cast-iron casing of the whole there is inserted micanite insulation. Over the cast-iron and round the gun-metal is moulded asphalte. Or the whole may be inserted in a tube recess cut in a block of granite or artificial non-conducting stone.

It is evident that the details of this design might be improved, and it is to be feared that the necessary electro-magnetic action is weak in proportion to the consumption of current spent in creating it.

The car carries no electro-magnets, but a small-capacity 500-volt secondary battery is needed on the car to pick up contact when, for whatever reason, this has been slipped.

21. The system invented by Messrs. Claret and Vuilleumier was the earliest in which all movable parts were removed from the immediate neighbourhood of the studs and the running track, and in which the switches were brought together in groups. A group of twenty contacts are set in a circle upon a horizontal circular entablature, in the centre of which is fixed a vertical pin. In outline this construction is shown in Fig. 110, in which T indicates the contact blocks, and the diagram Fig. 111 helps the explanation of its action. The apparatus is called a "distributor" or "distributing switch." Each contact, T, on the distributor is connected by a single lead to a *pair* of studs in the road. The collecting skate is long enough to touch two studs at one time, but not long enough to touch three studs simultaneously. A boss, mounted on the pin of the distributor, carries three arms, A, B, C, on the end of each of which is a contact brush or block. The middle brush A is wide, so that it can touch two fixed contacts T at once, bridging over the insulating gap between them. This middle brush is connected to the supply main. The

two outer brushes, B and C, are narrow, so that they do not bridge over this gap. They do not connect to the supply except through the car-skate. B and C lead shunt-currents from the track-studs to earth through the high-resistance coils of two electro-magnets, *b* and *c*, in the distributor, whenever either is connected to a stud that is alive. The boss carrying these arms is rotated, step by step, by a ratchet drive operated by a pawl on the end of a lever to which are fixed armatures pulled over by the electro-magnets. The lever is double-armed with a pawl at each end; but for progress in one direction only one pawl and one electro-magnet are operative. The

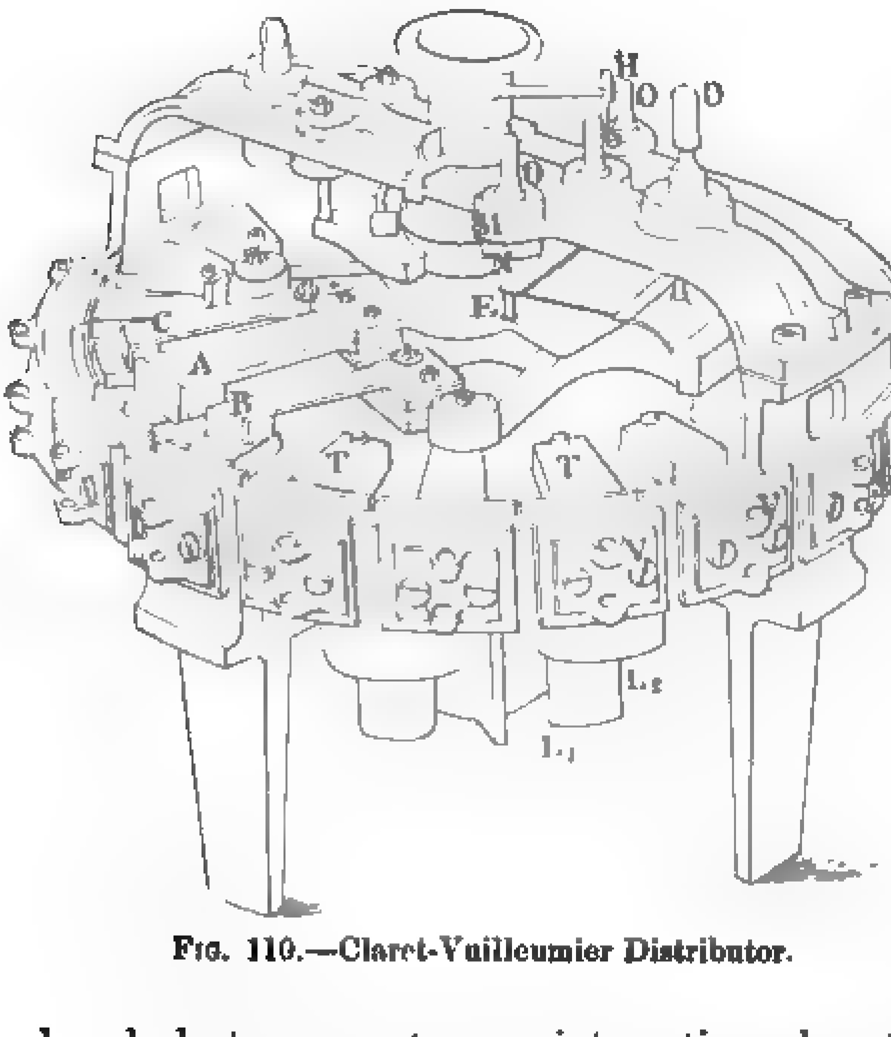


FIG. 110.—Claret-Vuilleumier Distributor.

other pawl and electro-magnet come into action when the direction of the car-travel is reversed, the whole arrangement being symmetrical back and forwards. The shunt-current through the operative magnet *b* is obtained during the first half of the distributor-stroke from the leading outer small brush, say B, and during its second half from the following brush, C. The change-over from one to the other brush is effected by a commutator over which the lever sweeps in its forward stroke. Its back stroke is actuated by a spring as soon as the magnet-coil loses current.

Referring now to Fig. 111, suppose the skate S to be in the

position shown by full lines resting on the two studs 9 and 10, which two studs are joined together by one conductor to the distributor contact 9–10, on which the brush A lies. The following brush C lies on the contact 8–7, which is joined by a single lead to the two studs 8 and 7; while the leading brush B lies on contact 11–12, joined by a common lead to studs 11 and 12. Neither B nor C is receiving any current, the only studs connected to the main supply through A being 9 and 10.

As the car advances in the direction of the arrow, the skate S passes out of contact with stud 9, and then comes into contact with stud 11. The leading brush B now gets current from A through the stud 10, the skate, and stud 11, the current passing through the electro-magnet *b* and thence to earth. The magnet so excited pulls over the ratchet lever, and so shifts the brushes from the positions

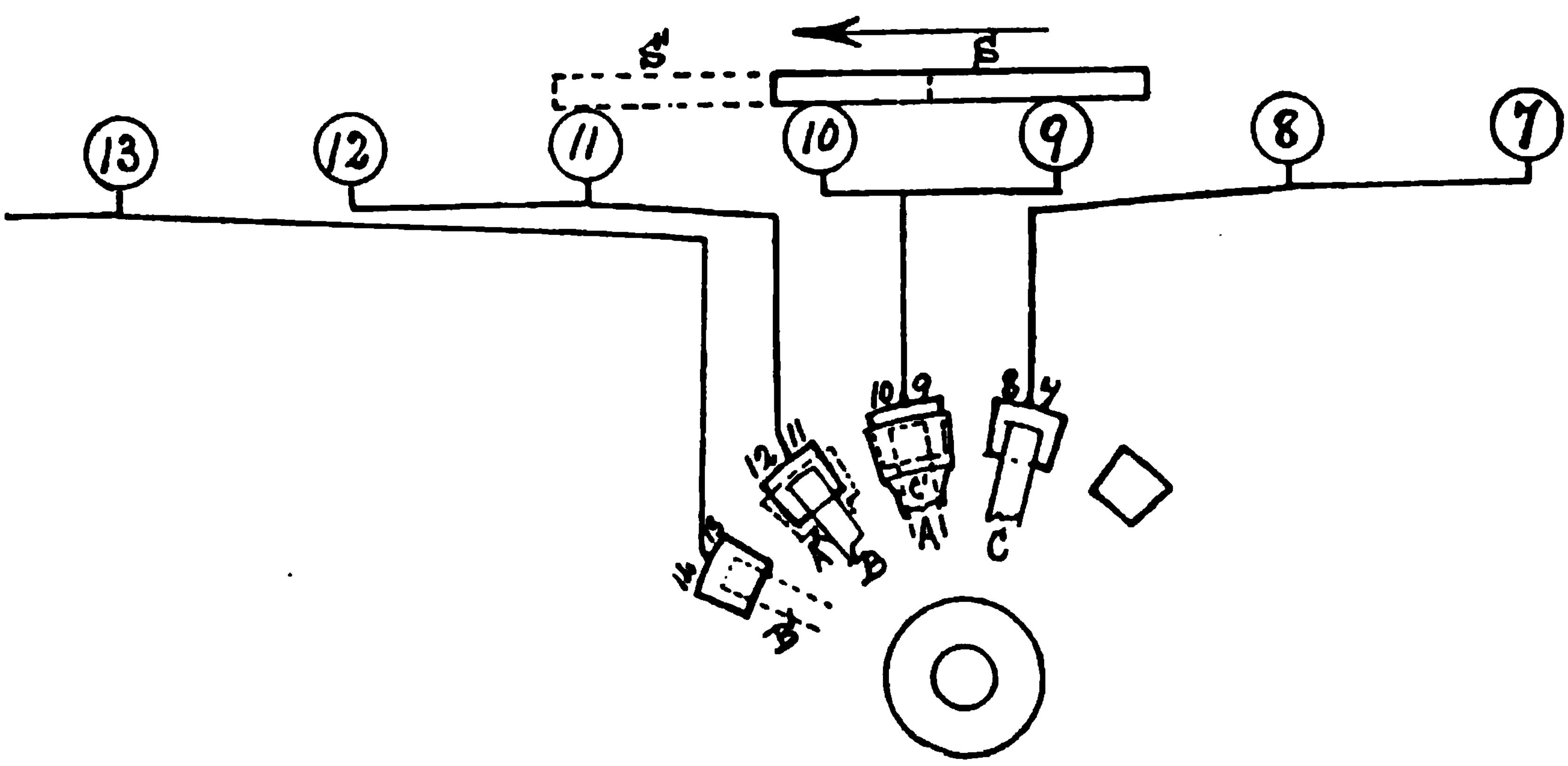


Fig. 111.

C, A, B to C′, A′, B′. In this motion A makes contact with the block 11–12 before it breaks contact with block 9–10. When A makes contact with 11–12 for the main supply through stud 11, it finds 11–12 already alive. After it breaks the main supply through stud 10 by breaking contact with block 9–10, this block is still at full potential, because the skate, which is already receiving current through 11, does not leave stud 10 until after brush A has left contact-block 9–10. This is ensured by making the ratchet motion so quick that the car at its highest speed does not keep pace with it. If the ratchet throw does not keep pace with the car, then there will be a break-spark in the distributor.

Before the brush A makes contact on 11–12, the leading brush B has left this contact, and it is not until after A touches 11–12 that the following brush C touches 9–10. There is therefore a momentary

failure to supply exciting current to the electro-magnet, and during this instant the continuance of the stroke of the ratchet gear depends upon its acquired momentum. This dead-point is at the middle of the stroke. Immediately this has been passed C comes in touch with 9–10, which is still alive, since the skate has not yet left stud 10. By the action of the commutator already mentioned a current through C to the electro-magnet is substituted for that through B; the magnet is re-excited, and pulls the ratchet lever over the second half of its stroke. As soon as the skate leaves stud 10 the magnet excitation ceases, and the ratchet lever is pulled back by a spring to its position ready for the succeeding stroke.

The brushes are now in the positions indicated in dotted lines, C upon 9–10 devoid of current, A upon 11–12 feeding from the supply to the car, and B upon 13–14, which remains dead until the head of the skate reaches stud 13, when the repetition of the action described commences.

22. The above-mentioned break in the magnet excitation at mid-stroke of the ratchet-gear throw is a defect in this system. Another defect is the possibility of the car overrunning the distributor. This possibility is independent of the use made of the car-motors, which may be cut out altogether without affecting the automatic action of the distributor through the skate. It may arise, however, either in consequence of excessive car-speed or from paper, wood, or other insulating material getting between a stud and the skate and causing failure of the magnet excitation. Anything that results in the car getting out of phase, or out of gear, so to speak, with the distributor, however, stops the action, which cannot be started again except by getting them into phase again either by pushing the car along the line to the stud corresponding with the position at which the brush A has stopped in the distributor, or else by opening this latter and rotating it by hand until its position corresponds with that of the car on the line. Either process is tedious and clumsy.

When a car passes out of the section connected to one distributor, it leaves the distributor in proper position to recommence its round whenever another car enters this section. The new car may enter from either end, as the gear is completely reversing in its automatic action. It moves in one or the reverse direction, according as one or the other of the two electro-magnets is excited, and this depends upon whether brush B or brush C is the leading brush.

But if a new car comes in the section, propelled by its own momentum or otherwise, while the previous car has not yet left that section and is being fed from the distributor, the new car is not only not fed as it comes into the section, but, when it has once entered, it is also out of phase with the distributor, and cannot be put into phase except by being pushed back to the end of the section.

This is a very serious defect in the Claret-Vuilleumier system. It is a defect inherent in every possible scheme of grouping the switches together in which it is endeavoured to make one moving part serve for making contact throughout the series of studs grouped together. In order to avoid this defect, it is essential to have an independently acting switch for each street contact. It may be convenient for certain purposes, or at certain places, such as sharp curves, to split the street contact between two or more studs spaced abnormally close. For each such pair or other group of studs acting as one contact there must be an independent automatic switch.

23. This fault is avoided in the Vedovelli design, the scheme of which is shown in Fig. 112. In this diagram the track-studs 9, 10, 11, etc., are on the paper spaced apart at the same distance as the

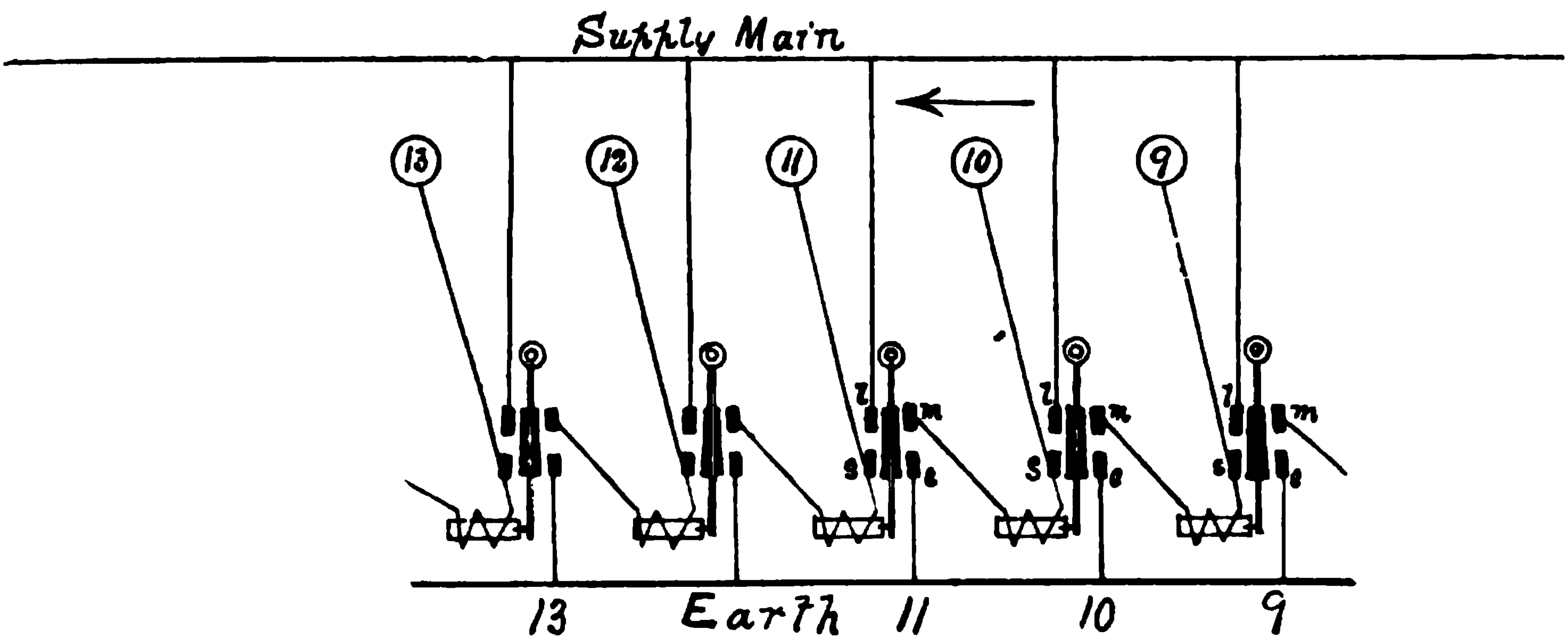


Fig. 112.

successive switches which connect them to the supply main; but it must be understood that the switches are small instruments grouped many together in one switch-box. From each a single lead makes a permanent fixed connection to its stud on the track. The terminal of the switch to which this lead is attached is also permanently connected to one end of the coil of the electro-magnet which operates the switch. From the other end of this coil a wire leads to one of the four contact-blocks of the *next switch ahead*. Thus, from stud 10 to contact-block s_{10} on to contact-block m_{11} there is continuous electrical connection. When no cars are passing all the switches lie over to the right hand in the diagram, with the cores of the electro-magnets pinned to them protruding from the solenoids. In this inactive position each switch makes contact between the blocks m and e, the latter block e being permanently connected to earth. The two other

blocks l and s are connected to the supply main and the stud respectively.

Suppose a car has advanced in the direction of the arrow-head so far as to be driven by supply through stud 9 and the car-skate. The skate is somewhat longer than the spacing between the studs, and it reaches stud 10 some time before leaving 9. Stud 10 is now charged to the 500-volt potential, and sends a small current to earth through s_{10} and $(me)_{11}$. This current excites the magnet 10, and its core is sucked into the solenoid and pulls over switch 10. This breaks the contact $(me)_{10}$ so as to demagnetize the solenoid 9 and release switch 9, which falls back to its inactive position, closing the contact $(me)_9$ to earth, and opening $(ls)_9$, so that stud 9 is no longer charged from the line. The movement of switch 10 also closes $(ls)_{10}$, thereby putting stud 10 in direct communication with the line. The skate and car-motor is now fed through stud 10. The last mentioned of the two effects of the throw-over of switch 10 occurs, however, before the first, the diagrammatic representation of the arrangement not showing this true chronological order of the events. That is, contact $(ls)_{10}$ is closed before $(me)_{10}$ is opened, and before, therefore, $(ls)_9$ is opened. Thus the feeding of the motors through stud 10 begins before stud 9 is cut off from the supply. The contact $(me)_{10}$ is broken, however, before the skate leaves stud 9, and, therefore, when $(ls)_9$ is broken, s_9 is still at 500 volts potential and the break in the switch occurs without sparking. There ought also to be no spark on the track-surface when the skate leaves stud 9, because stud 9 has ceased to feed before the skate leaves it.

The skate now continues to be fed through stud 10 so long as $(me)_{11}$ is closed, and this is not opened until after the skate has reached stud 11, excited the magnet 11, and closed the contact $(ls)_{11}$. The same process continues to be automatically operated in one switch after the other as the car advances.

24. An examination of the diagram will show at once that this progression can advance in the direction of the arrow only; it is not symmetric backwards and forwards, and will not maintain the automatic feed if the motors be reversed and the car moved backwards. This failure of automatic reverse operation is the most serious objection to this system.

25. Each switch is mounted in a separate portable box made of ambroin. The boxes are ranged together in two parallel rows in a trough-shaped casing, down the centre of which, between the two rows, runs a specially slotted mid-rib furnished with fixed contact knives. It is sufficient to put a switch-box in its place against this mid-rib, and to thrust down the junction-piece shown in Fig. 113, to make the proper connections with its two neighbour switch-boxes, with the stud, and with the supply line. A sliding-bar switch in

this mid-rib enables one to change these connections to the whole series of boxes for motion in one or the reverse direction; but such reversal cannot be accomplished except by opening the switch-trough and pulling this bar. Fig. 114 shows this mid-rib and one box in position.

The contacts are made by carbon blocks mounted upon a lever in such a way that, in coming together, the one face slides a short distance over the other, the object being to keep the surfaces clean by abrasion.

These two systems have different inherent faults, the Vedovelli in that it will not reverse, and the Claret-Vuilleumier in that the

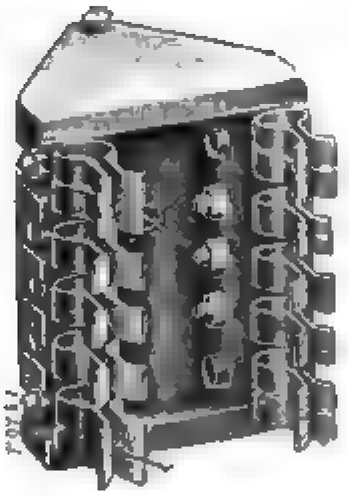


FIG. 113.

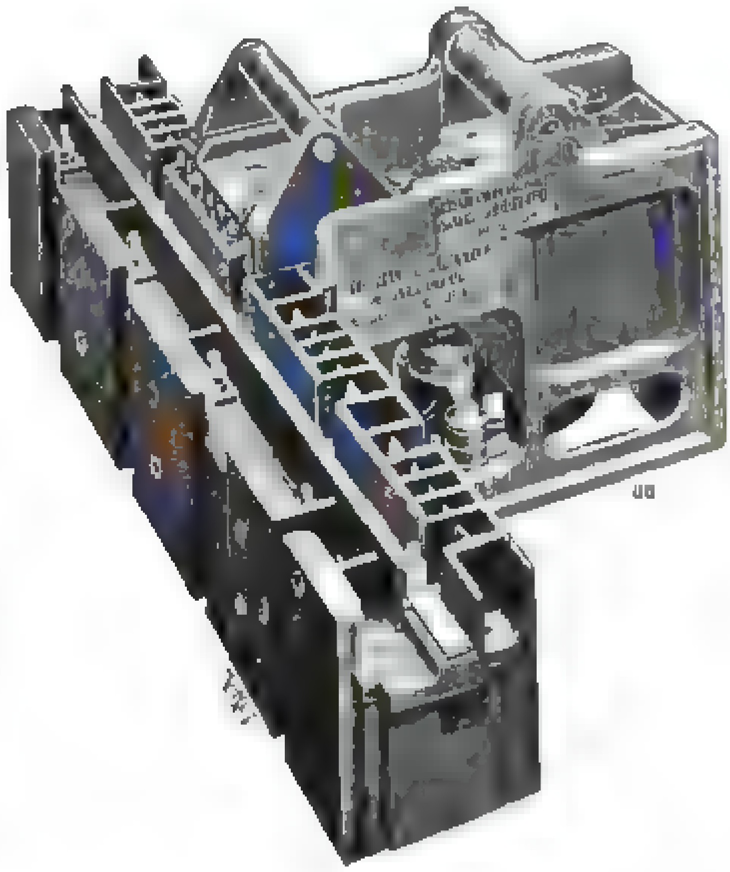


FIG. 114.

whole group of switches is served by one moving arm, so that one car only can be served at a time, and so that, if the car and the one arm get out of touch, there is no means of bringing them together again without great loss of time.

26. Both these defects are avoided in what is known as the Schuckert system, invented and patented by Mr. Paul. They are avoided at the expense of greater complication and greater cost, but in the result the working appears to be economical and very safe. It has been subjected to very prolonged experimental test in Munich, but has not yet found the opportunity for the commercial success which, in the writer's opinion, its technical merits deserve.

The trial line, as first laid down in Munich in 1896, gave trouble. Some of the switches stuck, and, during a thaw following a snow-storm, a stud, which was left charged owing to such sticking, led to the killing of a horse. This accident induced the authorities to prohibit further trials in their streets until the whole system had been rearranged, with the introduction of new safeguards.

Before this the electro-magnets which operated the switches were excited by the main working current; they are now operated by a shunt off the main current. The difference is obvious, and extremely important. The main working current taken into a tram-car is very variable. It is not only quite different during the starting period to what it is during uniform running, but it also changes as the load, the gradient, and the weather changes. During a portion at least of the braking it further becomes zero, as also when the car stands still. But the current, through a shunt of definite resistance, remains constant so long as the P.D. between the terminals of the shunt is unchanged. Switches operated by the main current taken into a car are thus of necessity subject to uncertain and unreliable action. Certainty and uniformity of action in the whole line of switches is of the essence of success; and a much greater chance of attaining it is afforded by the use of shunt currents, the shunt P.D. being from the full voltage of the main supply to earth.

From April 1 to November 27, 1899, daily trials were made in the Goethestrasse on the improved system, and, these proving satisfactory, on December 1, 1899, regular all-day running over the 2000-feet stretch was begun. Since then it has worked daily without accident. In outward appearance the change of system has been recognizable only by experts, firstly, because only a small proportion of the cars running over the trial length have been built for the new system, the others taking current by overhead line, which line, therefore, still runs over the 2000-feet stretch of contact studs; and, secondly, because the new cars themselves are fitted with trolley and pole, since they run long distances in either direction beyond the trial length.

Other minor improvements have been introduced since 1900, and it is sufficient to describe here the perfected form which the design now takes. Fig. 115 shows the scheme of the electrical arrangements.

In this diagram G is the generator at the central station; PP is the insulated supply main; *e*, *e*, *e* are the running rails—that is, the earthed return. If P and *e* be also taken as symbols for the potentials in the supply main and in the earth respectively, then $(P - e)$ is the available potential difference for driving the cars. S, S are the series of contact studs, from which working current is picked up by the collecting skate C; *s*, *s*, *s* are the switch terminals directly connected to S, S by copper leads.

27. Each of these leads requires such section as enables it to carry half the maximum current ever taken by a single car. In the diagram the switches are spaced uniformly along the line, they having the same spacing as the contact studs S. In reality, however, they are grouped, from twenty-five to thirty being brought together in one switch-box, placed at the side of the road away from the rail-track and the traffic. The spacing of the studs being about 10 feet, each switch-box serves a length of, say, 300 feet of tramway. The box is placed, of course, in the centre of the length it serves. Thus the length of copper lead from switch to stud varies from, say, 5 feet to 145 feet, not counting the transverse lengths due to the switch-box being placed at the side of the road and not between the rails on the line of the studs. The average length of these leads is thus 75 feet, and the total length of thirty of them is 2250 feet. Each, however,

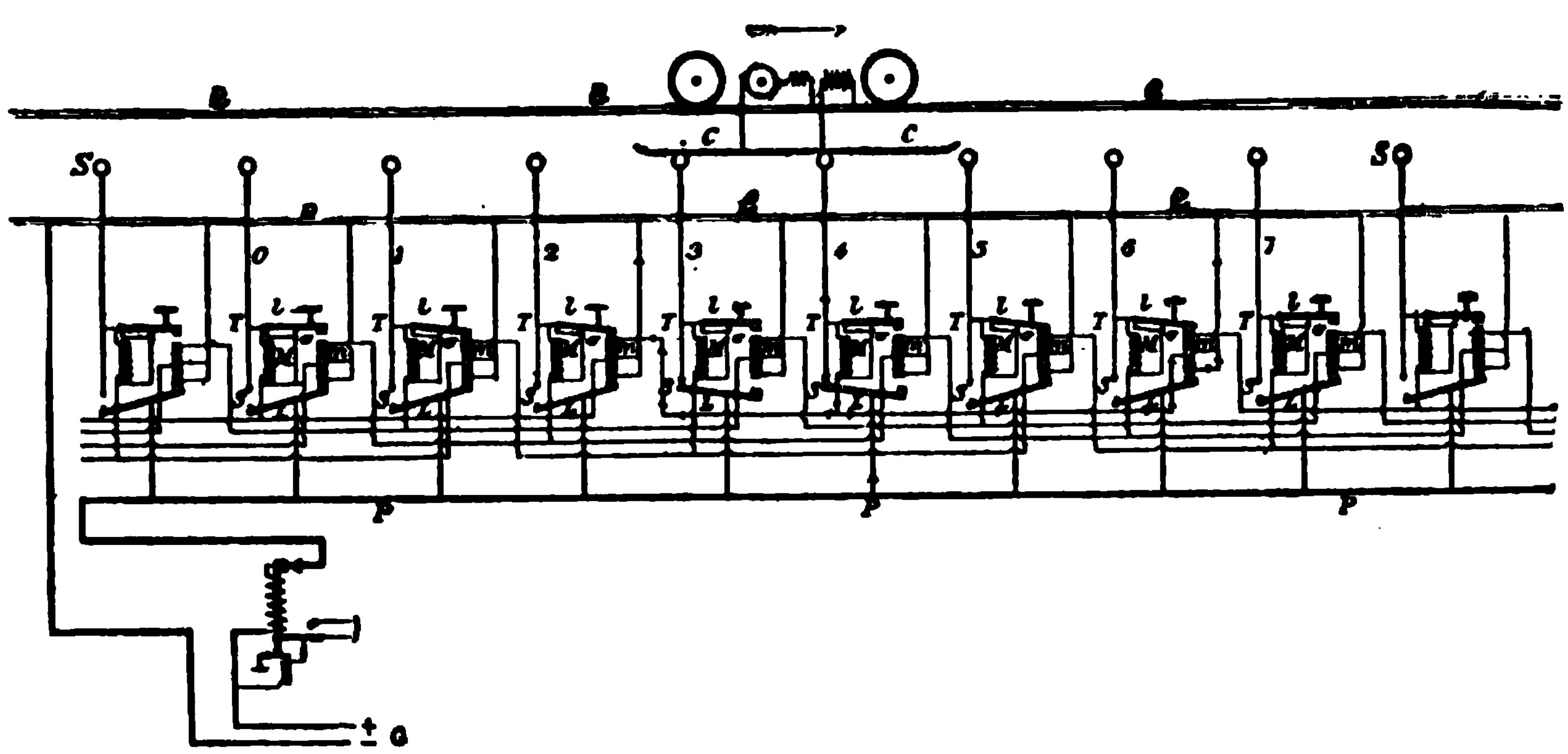


FIG. 115.—Diagram of Schuckert Contact Tramway System.

carries only half the current needed per car, so that the copper thus spent is equivalent to 1125 feet of the section needed for the whole current taken per car. This length 1125 feet = 300 feet × $\frac{30}{8}$; that is, the extra length of leads introduced by the system of grouping the switches equals the whole length of track multiplied by one-eighth of the number of studs served from each switch-box. As previously explained, however, the current density in these leads may be legitimately much higher than in the main supply cables, because the current passing through them lasts only a minute time during the passage of the car over the stud which is the terminal of each lead. Thus the leads are exposed to practically no heating, while the ohmic loss of power in them should be compared with the capital cost of the whole group of leads, and not with that of one lead only, in order to calculate the economical section.

The balancing advantage obtained from this system of grouping to set off against the extra expenditure in copper leads is the reduction of the number of switch-boxes to keep under supervision and repair. The time and cost of examining a switch-box to see if it be all right is practically the same whether the box contain one, three, or thirty switches. The number of switches getting out of order and needing repair per year, and the cost of such repairs, will be the same whether these be placed in 100 or in 3000 boxes along the line. Rather it will be less on the grouping system, because the one box containing thirty switches will certainly be of much better construction and be better set than would thirty boxes. Practically the thirty boxes can get no periodical inspection; they are almost necessarily placed so that they cannot be inspected except when such inspection becomes a necessity, that is, when it is found that one of them has got out of order. The inspection then taking place not only stops the traffic; it consists in a tedious search from box to box to find the switch that causes trouble. When thirty are grouped in one box so that the whole are exposed at once to view upon the unlocking of a single hinged door, the locus of the trouble is instantly detected, since it must be always apparent within which stretch of 300 feet of tramway the switch-sticking occurs; only rarely can there be doubt in locating it as between one switch-box and its next neighbour.

These advantages of grouping the switches increase with the number grouped together up to a certain limit, and at a less rate as this number becomes greater; that is, the extra advantage of grouping twenty instead of ten is greater than that derived from grouping thirty instead of twenty, while that from grouping forty instead of thirty is very much less. The extra copper expense of the branches increases in simple proportion to the number grouped together. Thus there is established a limit to the economy gained by increasing the number brought together in one group. The experience with the system is not yet sufficiently extended to supply data for determining this most economic limit.

It is to be noted that this extra expense in branch-leads depends on the spacing of the contact studs. Thus, if the length of line operated from one switch-box be 300 feet, and if the spacing be 10 feet, there must be thirty branches grouped together, and the factor explained above will be $\frac{30}{8} = 3\frac{3}{4}$. If, however, the spacing be 15 feet, only twenty will be grouped in one box, and this factor will be diminished to $\frac{20}{8} = 2\frac{1}{2}$. The possible spacing depends mainly on the length of the car, but it also depends a good deal upon the construction of the collecting skate hung underneath the car. Lower down are mentioned the improved skate constructions used by the Schuckert Company.

With a given length of collecting skate, the spacing required for the system now used by Schuckert, in which the skate always touches two, and intermittently three, studs, is just half that permissible with the system they used at an earlier date, in which the skate was always in touch with one, and intermittently with two, skates. But as in the new system the current carried by each lead is only half that carried by each on the previously followed plan, the change has made no alteration in the total necessary copper expenditure on the branch leads connecting switches with surface studs. It, however, doubles the number of studs built into the track, and also doubles the number of switches.

28. Returning now to Fig. 115, the design of the connections and the mode of action of the switches may be explained. Each switch is worked by two electro-magnets, M which makes contact to the surface-stud, and *m* which breaks this contact. The reference letters are seen on the larger scale diagram, Fig. 116, of one of the switches. There are two moving parts, diagrammatically represented by the two levers L and *l*. L is pivoted at its centre, while *l* is hinged at its left-hand end. Each forms a soft-iron armature, the opposite ends of L being alternately attracted by the magnets M and *m*; while the right-hand end of *l* is intermittently attracted by *m*, and, when current ceases to flow through *m*, is drawn back to normal position by a spring. L has permanent electric connection with the supply main P. The lever *l* is connected to the surface-stud S at T, this connection being also permanent.

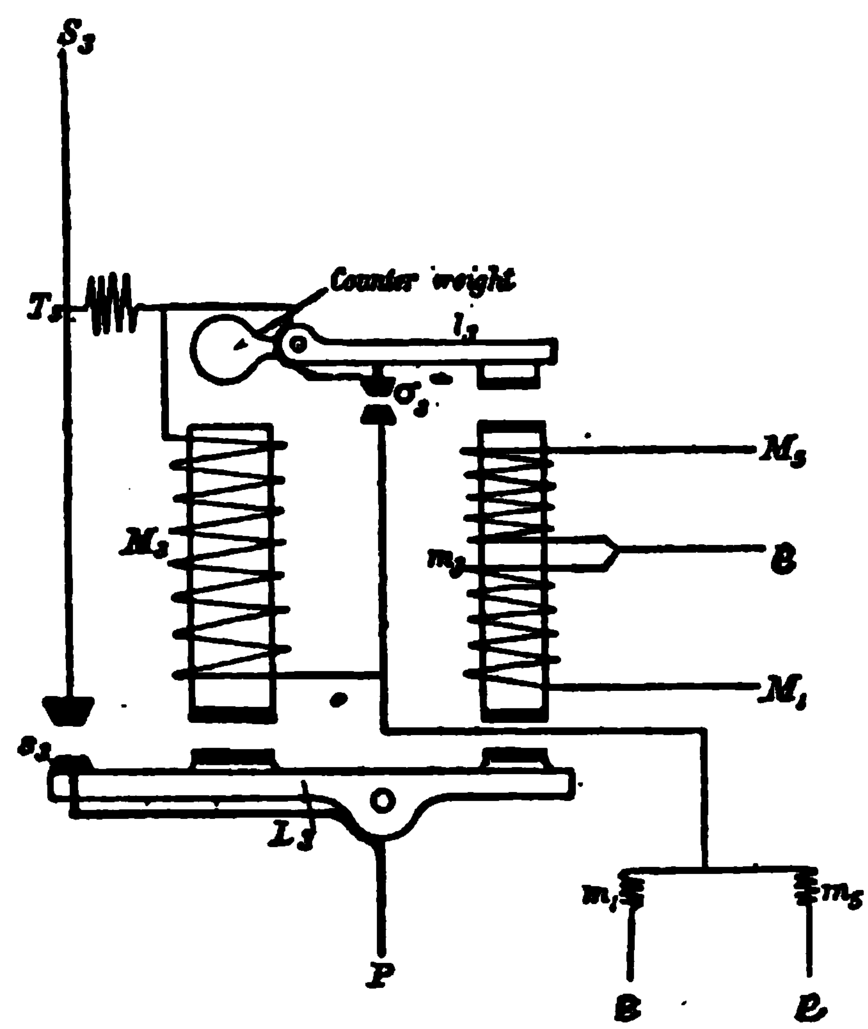


Fig. 116.—Detail of Switch.

M is magnetized by a solenoid current, which is a shunt from the terminal T between *s* and S to the earth *e*. Such current flows only when the connected surface-stud S is charged to the high potential. This charging of S takes place either through the closure of the lever L upon the switch contact *s*, or else through the collecting skate C and the other stud in contact with the skate.

The current magnetizing M may, however, be short-circuited through σ, the auxiliary switch contact closed by the depression of the

lever l. When this short circuit is established, M is demagnetized, or remains so feebly magnetized that a magnetic pull from m on the other end of L easily draws L away from M and breaks contact at s.

Beyond this short circuit the shunt current proceeds to earth, not directly, but through two branches, one of which runs backwards to the switch second behind, and the other forwards to the switch second in front of, the switch from which the shunt current flows. At these two switches, four steps apart in the series, the two halves of the shunt current run through the solenoids magnetizing the magnets m. Thus, the shunt current which magnetizes the main magnet M_3, after leaving this magnet, splits and magnetizes the two auxiliary magnets m_1 and m_5; while that passing round M_4 also magnetizes the magnets m_2 and m_6. From these auxiliary magnets the two branches of the shunt run straight to earth. Although the studs 1 and 5 are $4 \times 10 = 40$ feet apart, the fine, well-covered wires making these connections stretch only a few inches in the switch-box, so that the copper expense of making these connections is immaterial. Thus each auxiliary magnet m is wound with two coils, one in series with a main switch magnet two stud-spacings behind it, and the other in series with a main switch magnet two spacings in front of it. The magnet m is excited by current through either of these coils. It never receives excitation from both at the same time. Since its function is to attract either of two simple soft-iron armatures, it is not material that either excitation should give it a prescribed polarity; but if the two coils give it alternately opposite polarities, this will prevent all risk of its acquiring residual magnetism.

29. It is to be noted that all these connections are entirely symmetrical forwards and backwards. It results from this symmetry that the automatic action is continuously equally ready for either direction of car movement, and this without setting over any reversing lever. The only reversal needed is that of the motor.

30. At the instant, represented in the diagram, the skate C is in contact with the two studs S_3 and S_4, and the car-motors are taking current through both of these and the switch contacts s_3, s_4, which are closed, the magnets M_3, M_4 being both excited, and the magnets m_3, m_4 both idle, so that the levers l_3, l_4 are raised by their springs or weights, and the short circuits σ_3, σ_4 both opened. The shunt from T_3 through M_3 magnetizes the auxiliary magnets m_1 and m_5, holding the levers L_1 and L_5 securely in the positions which keep s_1 and s_5 open, while the levers l_1 and l_5 are held down, so that contacts are made for the short circuits σ_1 and σ_5. No current, however, flows through these short circuits, the terminals T_1, T_5 being neither of them connected to high potential.

The shunt from T_4 through M_4 acts in precisely the same way upon the apparatus at 2 and 6, which are at this instant in precisely

the same condition as those at 1 and 5. All four, the pair 1 and 2 behind the car and the pair 5 and 6 in front of it, are now in the same condition.

When the car has advanced so that C touches S_5, there is still contact between the C and S_3, the skate being made a little longer than two stud spacings. On touching S_5 this stud is raised to high potential through the skate, and therefore from T_5 there flows a current through σ_5 to the auxiliary magnets m_3 and m_7 and thence to earth. M_5 is, however, for the moment still unaffected, the shunt current 5 being almost wholly passed through the short circuit. The magnet m_7 being now excited, the lever l_7 is drawn down and the short-circuiting contact σ_7 is made, thus preparing the switch apparatus 7 and bringing it into the same state of readiness as that to which 6 has already been brought.

At the same time, the magnet m_3 being now excited, this draws down the lever l_3 and closes the short circuit σ_3. This deprives the magnet M_3 of current, which thus gives up its grip of lever L_3 and allows m_3 to pull over L_3 and break the main contact s_3. At the instant of this break current ceases to flow from S_3 to the skate C. But there is no spark at S_3 in the switch-box, because both carbons are kept at the same 500-volt potential by the continued contact of the skate with stud 3, the skate being charged from stud 4. It is important that the skate should not leave stud 3 before the switch contact S_3 is opened. The potential gradient is now reversed, and for the next small fraction of a second current flows from C through S_3 to T_3. From T_3 it flows in the same direction, and of the same magnitude, as before through σ_3 and thence to m_1 and m_5, the levers l_1 and l_5 being still held magnetically. This ceases, however, as soon as the skate end leaves the stud S_3. As it does so, the above reverse current, which is small because it passes through considerable resistances, is broken, the break occurring at the surface stud.

As soon as the surface break takes place the magnets m_1 and m_5 are demagnetized, and the levers l_1 and l_5 are raised. This throws switch 1 into wholly neutral condition. It at the same time breaks the short circuit σ_5 and throws the whole down current from S_5 to T_5 through the main magnet M_5, which, becoming now excited, pulls over the main lever L_5, since the magnet m_5 no longer holds this back. Thus the main contact s_5 is closed, and current now flows from the supply main P up to S_5, and thence through the skate to the car-motors. The current through C S_5 to T_5 which is at this instant reversed, is a small one, because of the fine wire resistances inserted in the shunt circuit. Contact is made at the surface stud before any main current runs through it. The main current contact is made in the switch-box, but the two carbons are already at the same high potential before the contact is made.

The six switches 2 to 7 are now in every respect in the same condition as were the six from 1 to 6 at the beginning of the period considered above. By repetitions of the process described, this condition advances automatically with the progress of the car along the line. The progression may be in either direction along the line without any alteration of the switch apparatus. Each switch apparatus has inserted in it a resistance which makes the shunt current operating it $\frac{1}{2}$ ampère under 500 volts; that is, the power needed to work each active switch is $\frac{1}{4}$ kilowatt, and as two are taking current at each instant, the power thus spent per car is $\frac{1}{2}$ kilowatt.

A minor criticism upon the system may be here stated. The above explanation of the action makes it clear that the supply of current to the motors through stud S_3 has ceased a measurable interval of time before the supply through S_5 begins. Throughout this small interval the whole working current passes through S_4. The criticism

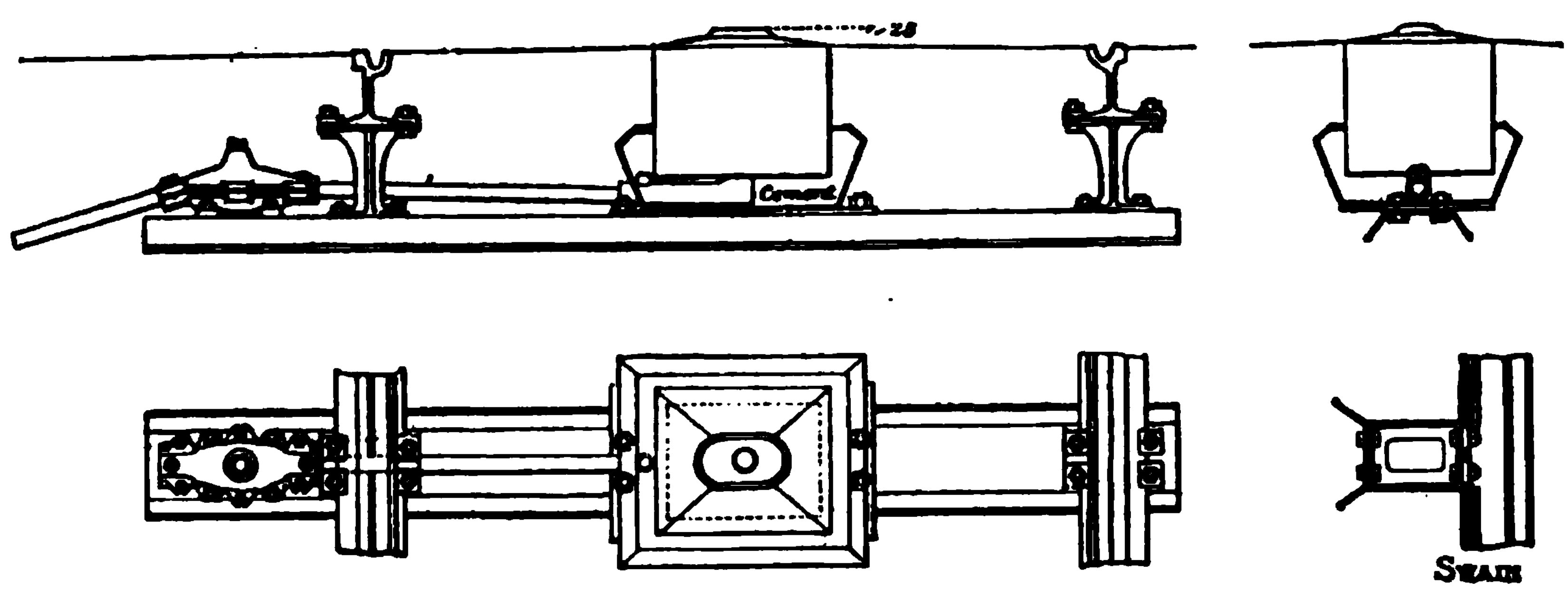


FIG. 117.—Surface-contact Stud.

is a small and non-damaging one. The overloading of a wire with current refers to the risk of over-heating. The heating takes time—it is a matter, not of ampères, but of watt-seconds—and if the overload lasts only for a fraction of a second, it requires an enormous overload to create risk of damage.

31. Certain safety appliances embodied in the Munich design will be mentioned lower down.

Fig. 117 shows in transverse and end sectional elevations, and in plan, one of the surface-contact studs with its setting. The stud is of hardened cast steel. It is let into a granite block, measuring 10 inches by $13\frac{1}{2}$ inches wide and $10\frac{1}{2}$ inches deep. This block rests on a cement bed in a sheet-iron box trough. This is bolted to a transverse steel sleeper which is hung by I-section distance pieces of the proper depth from the longitudinal rails. On the end of the sleeper is bolted a coupling muff, from which the lead is taken to the centre and up to the stud through a vertical hole bored in the centre of the stone. The block,

sleeper, muff, and connections are all finished and finally fixed together in the workshops, the only work done *in situ* being to clamp the whole to the underside of the two rails. The binding to the rails is very solid, and keeps the stud rigidly in its true central position and at its true relative level, which is about 1½ inch above rail surface. Fig. 118 shows one of the switches partially dismounted, and Fig. 119 shows it in completed form. The magnets M and *m* are both horseshoes, and are mounted on the wall-plate so that the pair of poles of each magnet lie at diagonally opposite corners of a square. The cores stand horizontally, and the armature lever L. which is shown detached in Fig. 118, is pivoted on a horizontal pin at the centre of the square. Its pole-pieces are attracted alternately to one and the other pair of diagonally placed cores. These cores project beyond the solenoids, and the lever lies between them, oscillating between them by a throw-over through quite a small angle. The main contact is made by a couple of carbon blocks, one fixed in an upward horn extension of the lever, the other fixed in a bracket from the wall-plate. The auxiliary lever *l* is acted on by one pole only of the magnet *m*. It lies horizontally under the square of four poles, and is drawn out of contact by its own weight instead of by a spring, as represented in the diagram Fig. 115.

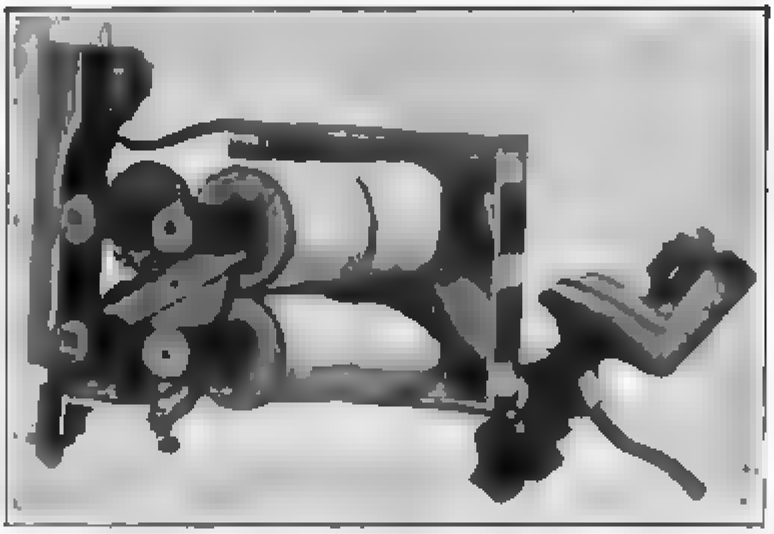


FIG. 118.—Part of Switch.

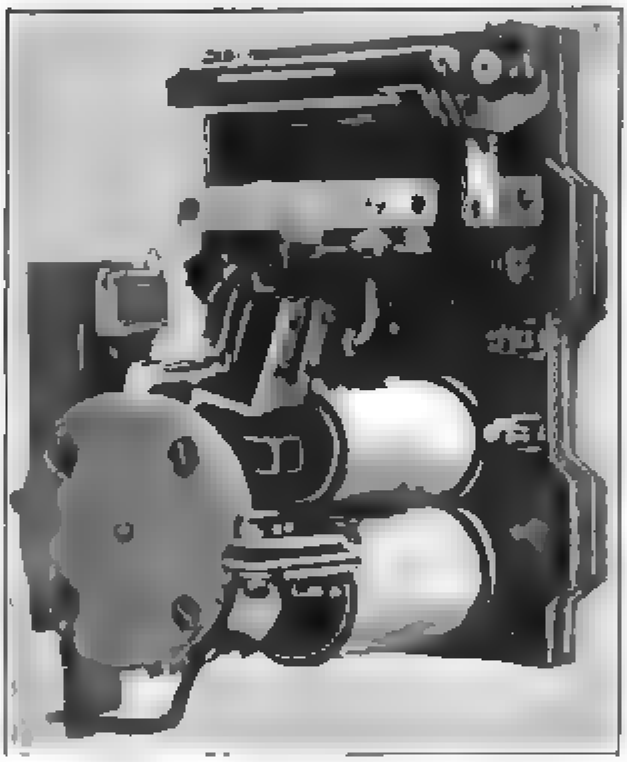


FIG. 119.—Complete Switch.

Test apparatus rigged up in the Schuckert works at Nurmberg kept a series of the switches constantly making and breaking contact under full current for many months. After between 50,000 and

60,000 makes and breaks, the carbons and all the apparatus were reported to be still in very good condition.

The wall-plate of each switch is pushed into and held by a spring clamp on the wooden inside lining of the cast-iron switch-box, which

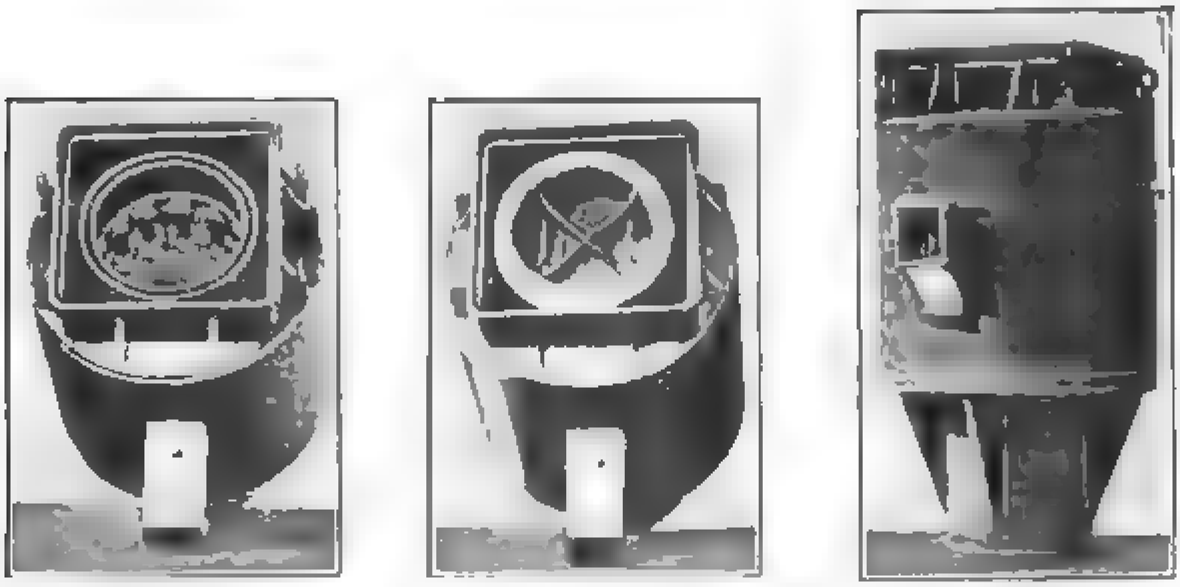


FIG. 120.—Switch-box.

is shown in Fig. 120. This box, holding thirty switches in three tiers, is of considerable size, especially as a hollow space is left between its outside walls and its wooden lining. It is large enough for a man to stand in it. It has a double-top cover, designed to make the

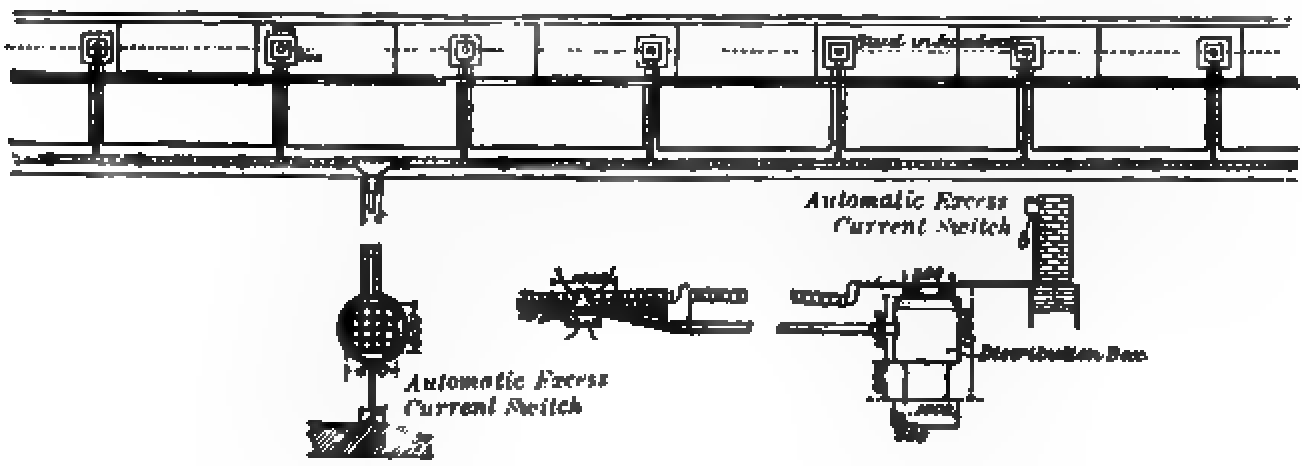


FIG. 121.—Distribution Box and Studs.

interior absolutely water and damp proof. Fig. 121 shows in plan and section the disposition of this box with regard to the tram-line and the leads to the surface-studs. The box in this case is sunk below the level of the foot pavement. Another form of box, allowing

it to stand above ground and giving access by a hinged side door, would, in permissible situations, have superior advantages.

32. It will be noticed that it is unnecessary that the car-motor should take any current in order to keep the switch apparatus working. This results from its being operated by a shunt taken to earth from a point outside the car. Thus the car may stand still or may run down hill or against the brakes without current, and it will still find the surface-studs automatically prepared to supply current to the motors. The use of a shunt also makes the correct working of the switches independent of leakage from the electrified studs to the rails, or even of any absolute short circuit between these.

When the car, however, is run from a place where the studs and switches have not been established—as, for instance, from an overhead line on to a contact-stud line, as in Munich, or after a cessation, from any cause, of supply to the main—the contact studs under the car must be energized from an external source. For this purpose the car carries a small accumulator battery, which, when it is connected to the skate, sends current through the two studs in contact to the magnets M, and thence to earth by the four magnet coils *m*. The magnets M pull over the two levers L, and communication with the main is thus established. The battery requires very small capacity, and in order to obtain the voltage needed in small bulk, the battery is made up for 20 volts, and this is transformed to 400 or 500 volts by a small rotary transformer mounted on the car and driven by the battery itself.

33. At Munich two new forms of collecting skate have been used. One consists of a chain having long, flat links and close joints. The other is a wire-brush collector of the proper width, and about 24 feet long. Both, and more particularly the latter, are reported to have given good results. Further improvements in this part of the construction of surface-contact trams are by no means improbable.

34. At the two ends of the car beyond the ends of the collector are fixed two "short-circuiting" brushes which sweep the studs as they pass. When either of these brushes touches a stud it establishes direct conducting connection between the stud and the rails, so that, if through failure of a switch a stud remains electrified after the collector has left it, a short circuit from supply main to rails is established. This short circuit is made to operate an automatic safety cut-out switch which cuts out the whole section. One of these cuts-out is attached to the section commanded by each distribution box. It becomes locked on coming into action, so that the section cannot be connected again until the whole of the distribution switches on the section have been opened. It is placed in a wall box, above ground, opposite the distribution box, as seen in Fig. 121, and can be opened only by a special key.

Independently of these safety brushes, the same magnetic cut-out

is brought into operation if three successive switch main contacts (s) are at any time simultaneously closed. It has been explained that, in normal working, s_3 is opened before s_5 is closed. If, through imperfect action, s_3 remains closed when s_5 is also closed, the whole section is disconnected from the supply main. If, on the other hand, the imperfect working, while leaving s_3 closed, also fails to close s_5, the successive working of the series of switches is interrupted, and the car ceases to receive current and comes to a stop, unless it be on a down grade sufficient for running by gravity alone.

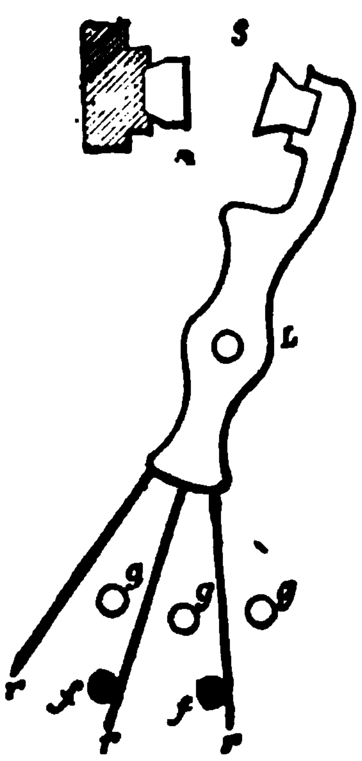


FIG. 122.

The automatic cut-out is double-wound, a current through either winding bringing it into operation. The one comes through the action of the short-circuiting brushes; the other through that of the last described safety appliance.

With these safety appliances the system is reported after two years' regular working at Munich, in a street that is said to be particularly muddy and badly paved, to be immune from danger through studs being left charged behind the car.

The *modus operandi* of these appliances may be simply explained by help of Figs. 122, 123, and 124. In Fig. 122 is sketched separately the main lever L, which closes and opens the main switch contact s. The spindle of this lever carries three small spring arms, r, r, r, in metallic contact with each other through their fixture on the spindle.

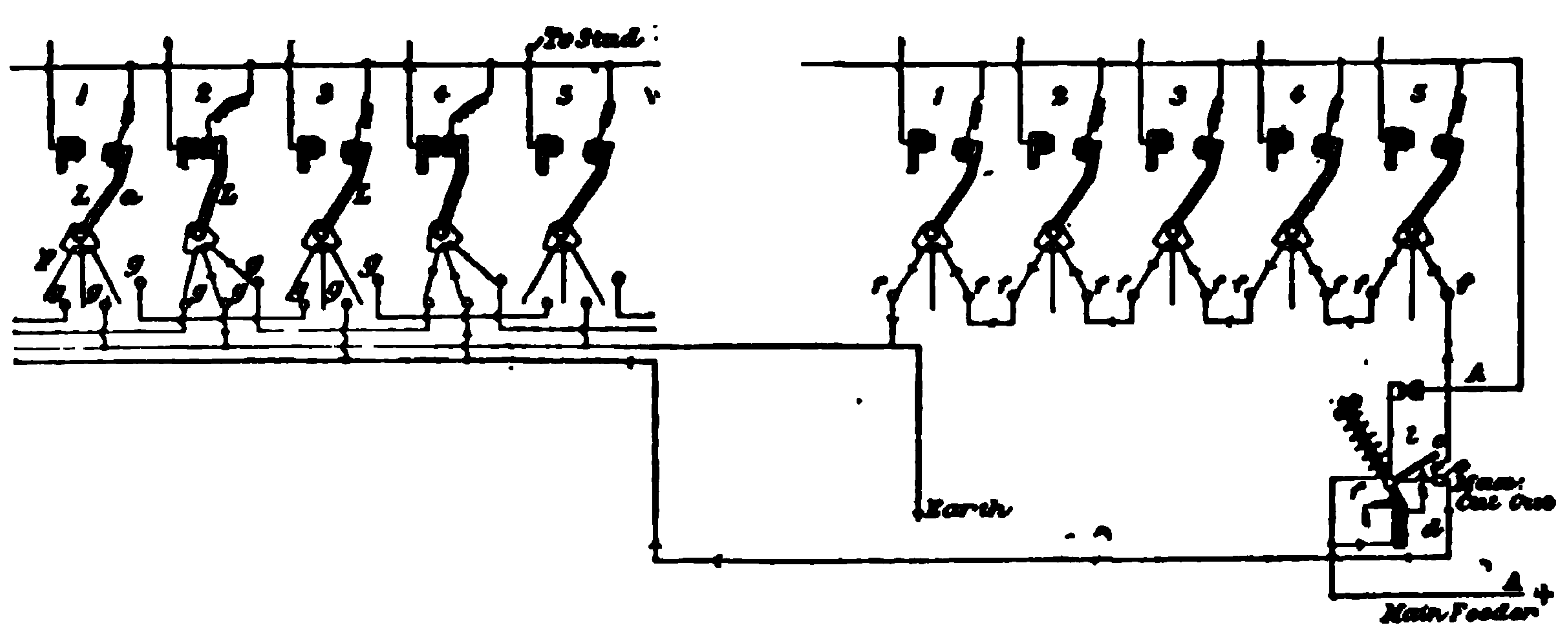


FIG. 124. FIG. 123.

When contact s is open two of these arms press against two metallic pins, f, f. As shown in Fig. 123, the pairs of pins f belonging to the whole series of switches in one distribution box are joined up so that when all these switches are open and all their arms, r, pressing against the pins f, a continuous circuit for a feeble current is formed from

end to end of the series. When contact *s* is closed the three small spring arms *r* press against three other metallic pins, *g*, *g*, *g* (see Fig. 122). The front pin *g* of the set on switch 1 is wired to the back pin of the set on switch 3, the front pin of 2 to the back pin of 4, and so on—as shown in Fig. 124. The middle pins of the switches 1, 2, 5, 6, 9, 10 are wired to earth; while the middle pins of switches 3, 4, 7, 8, 11, 12 are wired to the positive or out-lead of a shunt circuit leading through the safety cut-out switch. This connection is clearly shown in Fig. 124, the successive switches being taken in alternate pairs in this connection to the positive wire and to earth.

It will be remembered that the main contact *s* in switch 1 ought to be opened just before that of switch 3 is closed. If it remains closed after 3 closes, the automatic action is disturbed, and, in order to prevent the danger of leaving a charged surface-stud behind the passing car, there is need to call into action the safety switch. In Fig. 124 the arrangement just explained is shown to effect this result, the two switches 2 and 4 being drawn as simultaneously closed, and the effect being that shunt current passes from the positive lead through the middle and back spring arms of 4, and through the front and middle spring arms of 2, to earth. The shunt current, thus permitted to flow to earth, actuates the magnetic cut-out and stops the supply of main current to the whole section controlled from this one distribution box. It will be noted that this action will be unaffected by switch 3 being either closed or open, and that the simultaneous closure of any two following switches, such as 3 and 4, does not call it into play. The ingenuity and simplicity of the device are admirable.

When the cut-out has acted, the car-motors cannot obtain current again until the conductor has proceeded to the safety switch-box and closed the switch. For this purpose he carries a key enabling him to open the box, but this does not give him access to a hook-pawl which holds the switch open until the hook is released by a small electro-magnet energized by shunt current passing by the circuit shown in Fig. 123 and already explained. Any break in this circuit prevents him reclosing the safety switch. Such a break occurs until *all* the switches in the distribution box have been thrown over to the open position, as in Fig. 123. By this means it is made impossible to restart the car without ensuring that all the surface-studs upon the section are reduced to earth potential. After this is done and the safety switch reclosed, the employment of the accumulator battery carried on the car permits the motor to be restarted.

35. Figs. 125 and 126 are reproductions of autographic records taken in the Goethestrasse, of Munich, of the current supplied to a car worked by this system. Fig. 127 gives a similar record of current

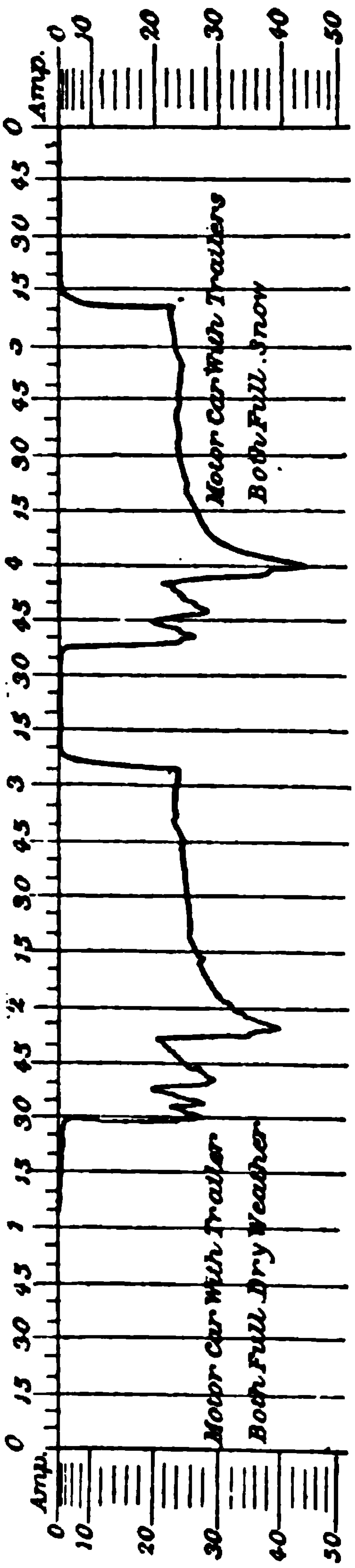


Fig. 125.—Surface-contact System.

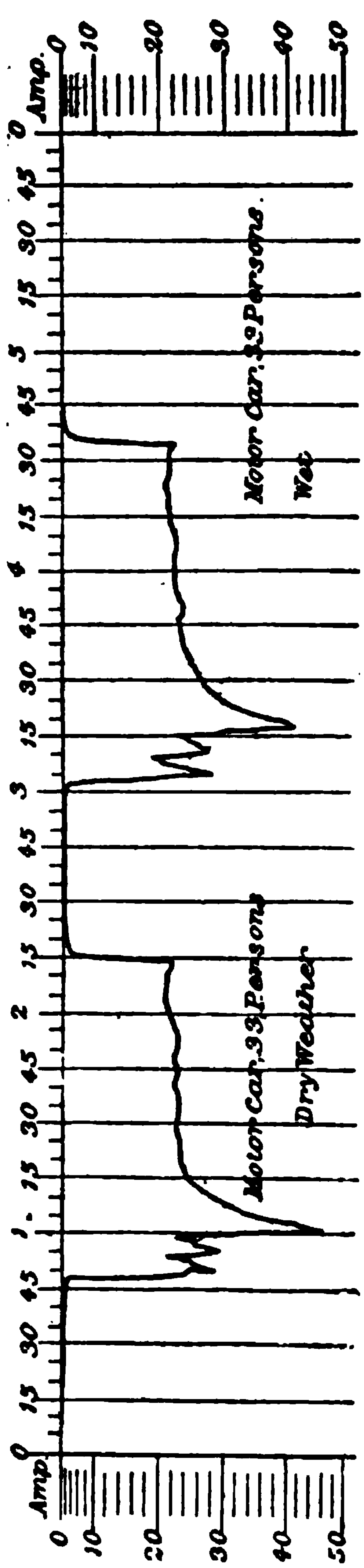


Fig. 126.—Surface-contact System.

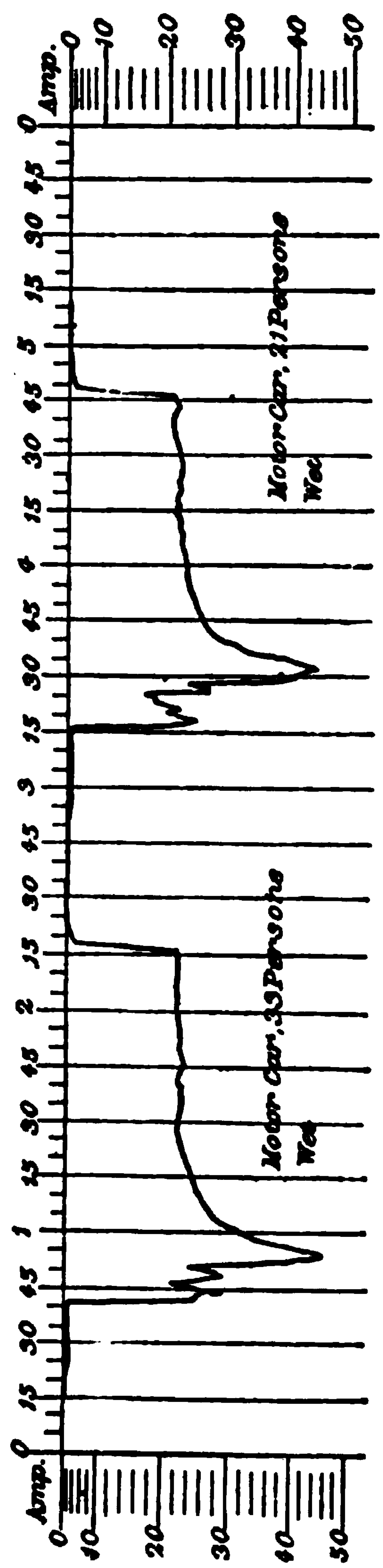


Fig. 127.—Overhead System.

taken by an identical car from the overhead line on the same stretch of street. It will be noted that the passenger loading in Figs. 125 and 126 is heavier than in Fig. 127. Fig. 125 refers to a motor-car and trailer-car together; Figs. 126 and 127 to a motor-car alone. The first two records show that the current consumption is not measurably affected by wet and snowy weather. The addition of the trailer also seems to make little difference in the current, and comparison with Fig. 127 shows the current consumption to be precisely the same whether taken from the overhead wire or from the surface-studs. It should be explained that the current recorded was not taken on the car itself, and includes all leakage in each case.

With thirty-three passengers the maximum current taken during starting and acceleration is 45 ampères. After steadying, it sinks to 23 ampères. In all the six records given the current follows almost precisely the same variations.

Respecting the applicability of the system in more northern countries, doubts have been expressed regarding its suitability for our English climate, on account of the damp of our fogs, mists, etc. Messrs. Schuckert answered this adverse criticism by placing a battery of the switches in a tank of water at the Glasgow Exhibition of 1901, where it was seen daily working regularly and well, fully and permanently immersed in water. Of course a small leakage occurred through the water, but it did not in any way affect the certain action of the mechanism. It must be remembered, also, that these switches are, in practice, ranged in a box that is made quite water-tight and even air-tight.

36. One further remark is needed to do justice to the system. The above description of the automatic progression of the switch action might possibly make it appear that the mechanism of this action is complicated, and therefore liable to derangement. The apparent complication lies, however, mostly in the difficulty in mentally following the action, and the tedious explanation of this action needed to make it clear. The actual mechanism itself is really simple; it has only two moving parts mounted in the most ordinary manner. It should also be remembered that, the switches being grouped in one box, the wire connections between them are all quite short and can all be overlooked as a whole at a single glance.

In conclusion, it may be interesting to give one word of explanation as regards the comparison between the phenomena occurring when the whole of the working current is broken at a switch, and that occurring when, as in the Schuckert system now explained, only half of it is cut off at one switch, to be immediately diverted through another channel, namely, through the switch second in front of that opened. The cause that makes the spark produced by breaking a circuit so much larger than that occurring on closing the same is the

self-induction of the circuit. Now, in the diversion of one-half the current from one branch lead to another, the self-induction involved is only that in the small part of the total circuit made up of the two branches in question, or, otherwise expressed, the self-induction only of the sub-circuit, or loop, formed by the joining up of the two branches. The spark caused by this diversion is thus very small as compared with that caused when the current is cut off altogether from the motor.

The usual statement of this explanation is that no spark occurs when the same potential is maintained at the two contact surfaces after they have separated as before the break. This may be taken as a shorthand mode of expression; it is not entirely complete or accurate, but is sufficiently so as to prevent its being misleading. There is no doubt that a spark is a current, and that no current flows except along a down-grade of potential. A spark is a momentary current driven across a high-resistance gap by a large difference of potential. If it were exactly true that the two surfaces of the switch maintained during the instant after separation their previous equal potentials, then no spark would occur. But the self-induction in the loop above referred to, excited by the change in the distribution of current round it, and lasting only while this change is taking place, does produce a momentary difference of potential between the separating switch surfaces; and a spark of length proportional to this self-induction, and therefore proportional to the current itself, must occur. Actual observation, however, shows that the spark so caused in the apparatus now under consideration is so small as to be invisible and entirely harmless.

37. Two systems involving double rows of track-studs have been designed by the Westinghouse Co., and by Stobrawa, of the Helios Co. As these are not much in use, they need no more than mention here. Neither need any description of the Lorain system, which has been installed in Wolverhampton, be given. It is said to have given much trouble in the streets through the number of studs left alive behind the cars.

CHAPTER VII

LONDON DEEP-LEVEL ELECTRIC RAILWAYS

1. Distinction between Railways and Tramways—2. Deep-level Tubes in London Clay—3. Excavation of Central London Railway Tubes—4. Central London Railway General Plan and Profile—5. Central London Railway Running Rails—6. Central London Railway "Third" Conductor Rail—7. Central London Railway Tunnel—Greathead Shield—8. Station Tunnel Shields—9. Setting out Tunnel Line and Alignment of Shield—10. Station Shafts—Excavation and Tubbing—11. Station Lifts and Winding Machinery—12. The Bank Station—13. Electric Locomotives—Vibration—14. Motor-car Trains—15. Motor-truck—16. Driving Cab and System of Control—17. Energy Consumption—18. Analysis of Energy Expenditure—19. Sub-station Transformers and Converters—20. Tunnel Ventilation—21. Central Station Generators—22. Central Station Engines—23. Central Station Boilers—24. General Arrangement of Power Station—25. Baker Street-Waterloo Deep-level Railway—26. Charing Cross, Euston, and Hampstead ditto—27. Depths and Gradients in ditto—28. Brompton and Piccadilly ditto—29. Great Northern and Strand ditto—30. Great Northern and City ditto—31. City and Waterloo ditto—32. City and South London ditto—33. Rates of Boring Progress with Hand and with Machine Excavation—34. Price's Digger Shield—35. Boring under the Thames.

1. Much of what appears in previous chapters applies to railways as well as to tramways. In Chapter I. we endeavoured to define the distinction between railways and tramways. According to that definition, the King's Way subway described in Chapter V. is a railway; but, as it is merely one link in an extensive system of ordinary street conduit tramways, it is quite certain that it will be commonly referred to as a tramway. It is an instructive case of intermediate character. Although at the moment of writing this it has not yet been finally determined whether conduit and plough collection of the current will be used, still it is safe to predict that this will be the case provided that the same system be used throughout London north of the Thames. It would be extravagantly uneconomical to provide all the cars running from the northern districts to the King's Way with apparatus for two different methods of current collection; while it would also be considered in London as intolerably inconvenient to the passengers to compel them to change cars for the purpose of running through this half-mile of subway. Therefore, the

FIG. 128.—General Plan of the Central London Railway from Shepherd's Bush to the Bank, with Enlarged Plan of the Bank Subways.

same system will be, or ought to be, adopted in the subway as throughout these northern districts. But, except for the sake of such uniformity of system, the conduit is an entirely wrong construction for the subway, as its extra costliness carries with it no advantages of any kind in this situation. An overhead wire, or a "third-rail" conductor, is clearly the best and most economic plan upon all railway tunnel-systems.

2. When fully developed, the London electric railway network will unquestionably be the most important urban system in the world, and, therefore, although it may be said to be still in its infancy, it is given a first place in this volume. The first line completed was the "City and South London" line, and the second that between the "City and Waterloo." Both these lines will receive mention below, but it will be convenient to commence with a description of the "Central London." It is not only more modern in its design, but the conditions under which it has been constructed are more nearly the standard conditions for the bulk of future deep-level work throughout London.

All the three lines above mentioned are deep-level tunnel railways. Later on we will describe the great development that is now being carried on throughout London on this system. It is peculiar to London because of the special geological position of this part of the Thames valley. The special feature is the deep bed of tough "blue London" clay that everywhere underlies the loose surface strata of gravel and sand. This clay bed varies in thickness from 60 to 400 feet; its upper face is at places close to the surface, and its lower face is nowhere less than about 70 feet below the surface, and in most places much deeper. The clay is of a blueish-grey colour; it is fairly plastic and very easily cut; but water will not pass through it, and in the mass it forms a secure foundation, except where so close to the surface as to be affected by annual variations of temperature in the supersoil and by the atmospheric oxidation of the iron it contains in the form of carbonate. Such weathering rapidly turns the colour to a light brown and destroys the tenacious and impermeable character of the clay. At the surface it cracks, and the entrance of surface water through these cracks causes it to swell, and thus heave and sink, usually twice a year. These effects, however, penetrate to small depths only, and at the deeper levels no more ideal substance for boring tunnels in could be imagined. The tunnels, driven at an average depth between 80 and 90 feet below the surface, very seldom run out of this blue clay, and so long as they leave a margin of 2 or 3 yards between the excavation and the clay surface there is no trouble with water. In the clay are embedded rounded masses of limestone and argillaceous limestone. These are for the most part small, being sometimes only 3 or 4

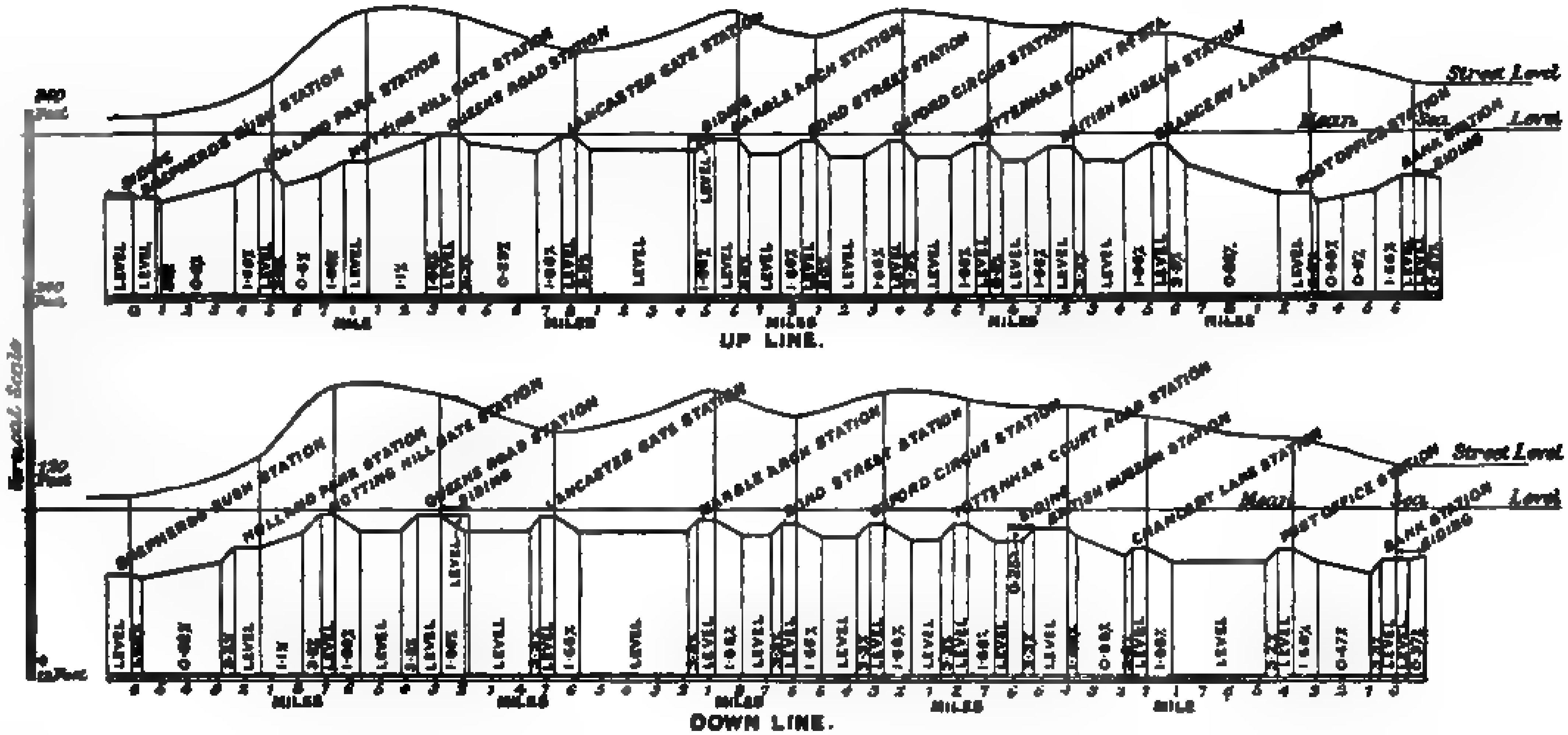


Fig. 129.—Profiles of Up and Down Lines, Central London Railway.

inches in diameter, but occasionally they are over 3 feet in thickness. These cause only slight trouble in excavation, being usually picked out easily when part of the clay in which they are bedded has been removed.

3. Nearly the whole of the Central London tunnel was excavated by hand-pick. Almost all the work now being carried out is done by a special boring-machine, which will be described later on. With hand work the help of a Greathead shield is necessary. With the boring-machine the shield is also commonly used, but in dry places it can be dispensed with. With hand work the progress varies from 65 to 85 feet length of 12-foot tunnel per week in the absence of accidents which stop work for repairs, etc.

4. Fig. 128 is a map of the Central London line, and Fig. 129 is a section showing the gradients and depths below the surface of the up and down lines, which are in separate tubes. The line stretches in an almost straight line from Shepherd's Bush to the Bank, by way of Bayswater Road, Oxford Road, Holborn, and Cheapside. It is almost exactly 6½ miles route-length, including the sidings at either end. The generating station and car works and stables are at Shepherd's Bush, and there are thirteen passenger stations including the two termini. The average of the twelve distances between stations is 0·54 miles, or 950 yards. Four of these distances are over 1000 yards, and the least is 640 yards. At each station there is a level length of about 320 feet stretching equally in either direction. The approach to each station is an up-grade of 1 in 60 through from 500 to 600 feet, and the departure from each station is down a gradient of 1 in 30 throughout from 240 to 300 feet. Thus the stations may be regarded as set upon hillocks 8 to 10 feet high above the intermediate mean grade-line. The 1 in 60 climb up this hill is eastwards in the one tube and westwards in the other. At each station the two tubes are brought to the same level, except at the Post Office, Chancery Lane, and Notting Hill Gate, where, on account of the narrowness of the roadway, the one tunnel is placed nearly on the top of the other. The gravity resistance on the climb through 600 feet length into each station lessens the braking work required for quick stopping. The run down the 1 in 30 incline greatly assists the motors in effecting a rapid acceleration of speed in the first 100 yards of each journey. The longest intermediate length between the hillocks is just under 1000 yards, while the shortest is 340 yards. On these intermediate lengths the gradients are small and unimportant, the greatest being 1 in 90. They have for object to avoid unnecessarily deep station-shafts by following the ground surface in some degree, and to avoid running into water-bearing strata. At Shepherd's Bush, Queen's Road, and Marble Arch there are cross-over tunnels, as also sidings to accommodate two trains.

5. The return current passes by the running rails, which are bonded to the iron lining of the tunnel. Fig. 130 shows the rail-section used throughout the tunnel, except at crossings and points where the bull-headed section seen in Fig. 131 is used. The weight

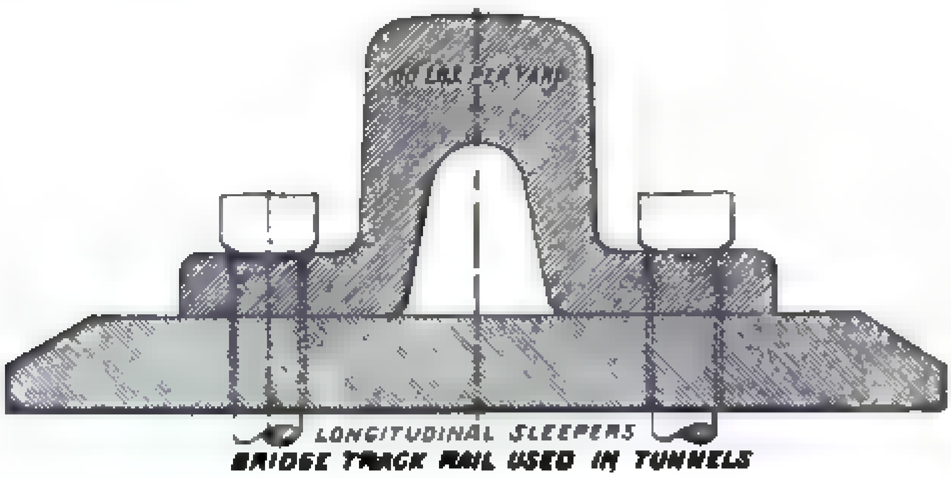


Fig. 130.

of either section is 100 lbs. per yard, and they are rolled in 60-feet lengths. They are laid on longitudinal timber sleepers embedded in concrete. The copper bonds have a section of 0·31 square inch, and every pair of rails is cross-bonded. Wherever the iron tunnel-lining

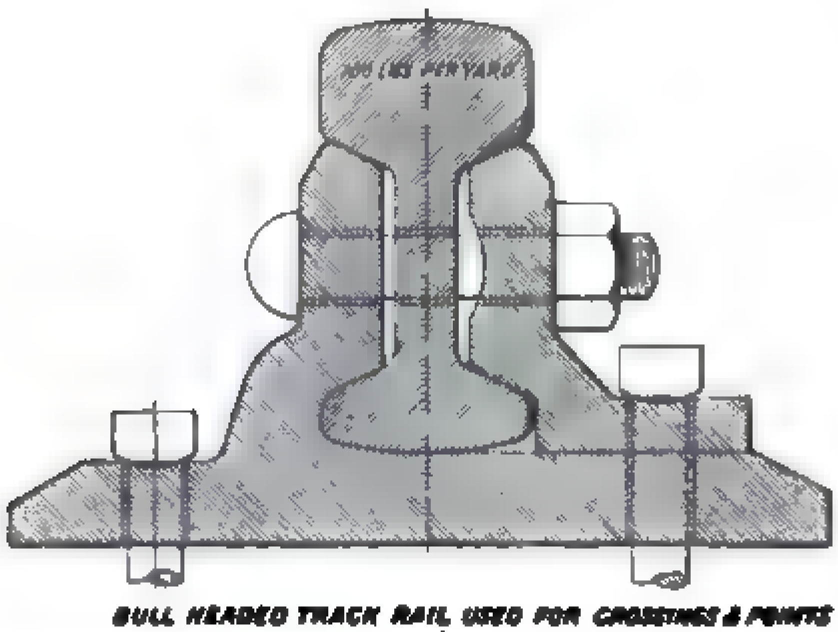


Fig. 131.

is interrupted by brick or concrete partition walls, the two parts are bonded with flat copper strip. According to test, 4½ miles of completed tunnel and rail of the two tracks had a resistance of $\frac{1}{50}$ ohm, or $\frac{1}{225}$ ohm per mile. The rails alone would offer three times as much resistance, so that the tunnel-lining and the enveloping clay

carry about two-thirds of the return current. Nevertheless, the traffic is at certain hours so heavy that the drop of voltage along the return sometimes equals the B.T. limit of 7 volts.

6. The supply of current is by a steel central third-rail, of section shown in Fig. 132. It is of simple channel shape, weighs 85 lbs. per yard, and is carried on porcelain insulators bolted to timber cross-sleepers. These are spaced $7\frac{1}{2}$ feet apart, and the length of the third-rails on straight runs is 42 feet, and at other places sometimes as short as 30 feet. The bonding is by four copper Crown bonds at each joint, of a combined section of $\frac{3}{8}$ square inch. The resistance is $\frac{3}{80}$ ohm per mile.

The current taken to the motors is 500 volt continuous. It is brought from sub-station rotary converters, which are fed by 3-phase current at 330 volts between each pair of phases from static transformers. To these the energy is supplied from the Shepherd's Bush generating station at 5000 volts in the form of 3-phase current of a frequency 25 per second. The high-tension feeders are brought along the tunnel as 3-core cables. Each core is paper-covered, the three bound together and covered with jute, this being again wrapped in paper and covered with an outside protective lead sheath. The manner of suspending these cables by brackets to the side of the tunnel is shown in Fig. 133. Two such cables run from Shepherd's Bush to Marble Arch, each core having a copper section of $\frac{3}{16}$ square inch as far as Notting Hill Gate and $\frac{1}{8}$ square inch thence to Marble Arch. From Marble Arch to the Post Office sub-station, a single cable of the smaller section suffices. Throughout the length these cables are protected by a continuous sheet-steel guard pinned to the brackets.

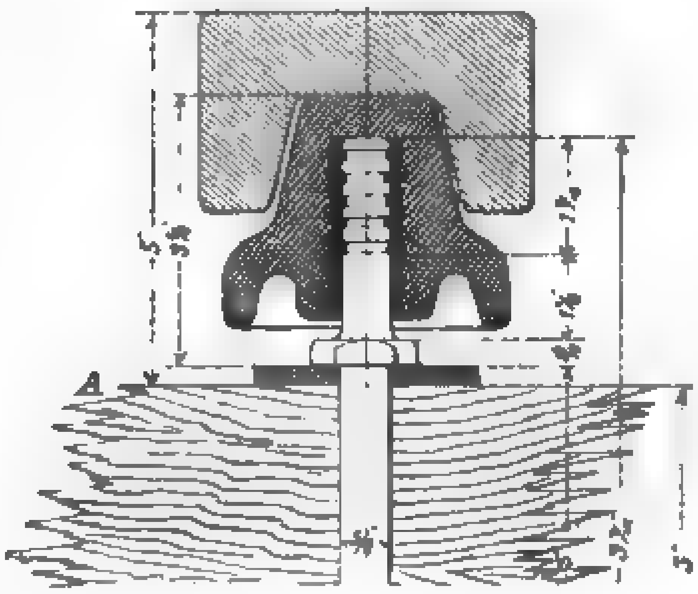


FIG. 132.—Section of Third Rail and Insulator.

7. The tunnels are circular in section. The main lengths are 11 feet $8\frac{1}{4}$ inches in diameter outside the ironwork, but at sharp curves the larger size, 12 feet 7 inches, is employed, and an intermediate size, 12 feet 5 inches, is also inserted in many places. The centre-core is dug out with pick and shovel. Round about the hole so made large masses are broken down by the driving forward of a ring of steel-pointed piles. The points of these travel a short distance

in advance of the cutting edge of the Greathead shield, and are driven forward by hydraulic rams simultaneously with the shield. The shield is a very strong cellular steel structure in the form of a short cylinder, of diameter about 3 inches larger than the iron skin of the tunnel. Its back end is freely open for access by the miners. Its front edge forms a keen circular knife-edge. It carries six hydraulic rams of 7 inches diameter, the ram cylinders being mounted on the shield and their plungers issuing horizontally backwards. Timber packing being placed between these rams and the flanges of the completed iron tunnel, when high-pressure water is admitted to the cylinders the shield is thrust forward and pares out a "finishing cut" of 3 or 4 inches of clay, thus bringing a section of the tunnel to the exact correct shape and size. After the shield is pushed forward the section of the clay boring which it leaves uncovered behind it is immediately built over with massive cast-iron "segments." These are 20 inches wide in the direction of the length of the tunnel, and, on the average, each push forward of the shield measures exactly 20 inches. In the size of tunnel now under mention six such segments and a 10-inch cast-iron key-block complete the circle. They are built in by being bolted to each other and to the flanges of the last erected ring of segments. The clearance space left outside between them and the clay wall cut by the shield, from 1 to ½ inch thick, is filled in with quick-setting hydraulic lime grouting squirted in under pressure through certain holes left in the segments for this purpose. Later on similar details will be fully illustrated in connection with the tunnel railways now being bored in many lines under London. Each segment weighs about 6 cwt., and is most expeditiously put in place by hand-lifting by four men. Hydraulic lifters, however, are used for the larger sizes of tunnel.

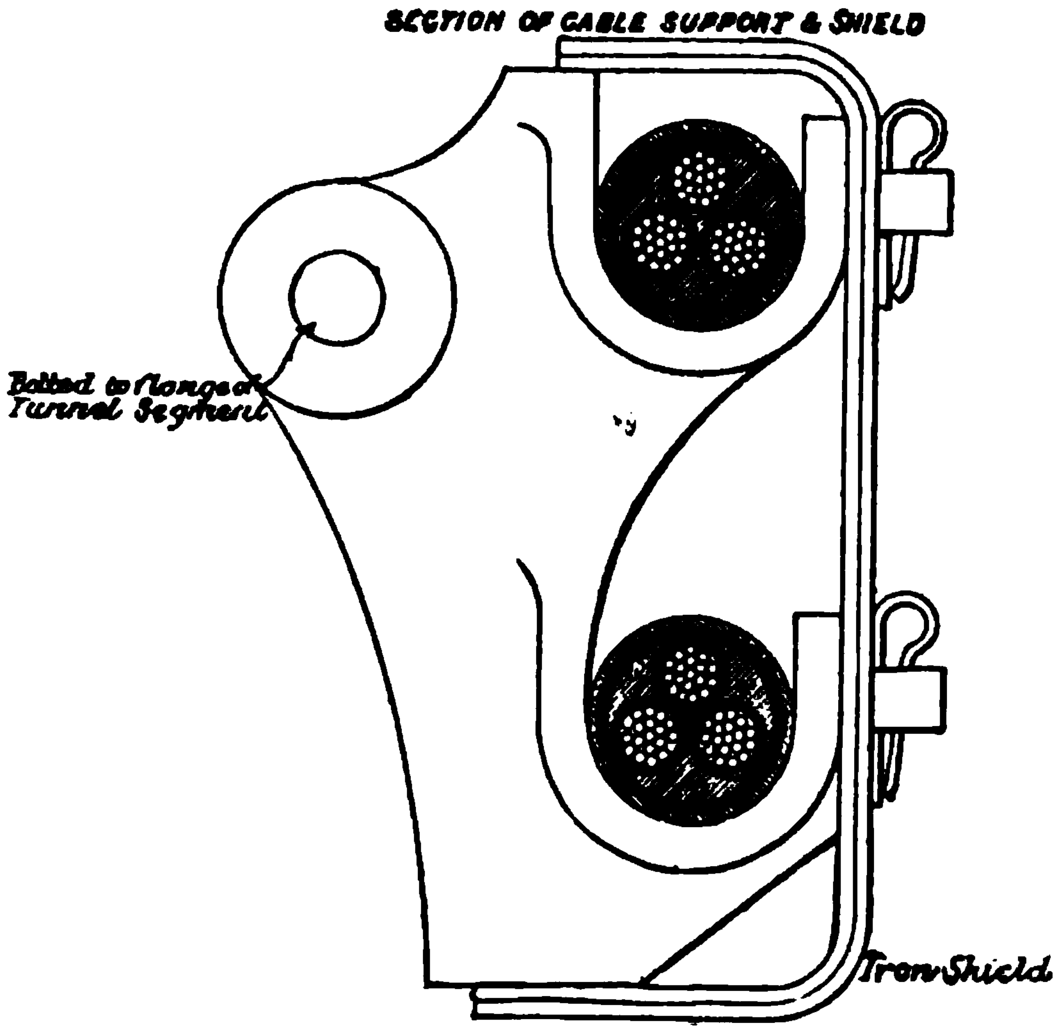


FIG. 133.—High-tension Feeder Cables.

8. At the stations the size of the tunnel is 21 feet 2½ inches, and 25 feet in the cross-over tunnels connecting the two running tracks.

In these the number of 7-inch rams employed to push forward the shield was 22. In the large shields the face is crossed by two pairs of strong steel bridges, and these carry four "face-rams," which are hydraulically pressed up against the clay face and obviate the risk of the whole falling down at the wrong time. The bridges form two platforms, and divide the whole working face into nine sections, each large enough for two miners to work at.

In passing through strata where there is no risk of water, the Greathead shield may be quite open in front. It is always constructed, however, in such manner that it may be very rapidly closed in the event of water unexpectedly appearing. In working through water-bearing strata its front portion is constructed as an air-tight chamber, access to which is gained through an air-lock, and into which is pumped air at whatever pressure may be needed to keep back the water. Unless the whole superincumbent strata be of gravel, this pressure is never so great as would be needed for working under pure water at an equal depth below the atmospheric surface. Only at one point in the 6½ miles of the Central London Railway was air-lock work of this kind required. The absence of water makes a very great difference in the cost of the work per yard forward.

9. As the work of boring each tunnel section proceeds, its forward direction has to be set out, both in plan and elevation, with scrupulous care. This direction is practically and ultimately determined by the direction of the cut taken by the forward edge of the shield; and this changes with any small tilting of the shield by the greater or less advance of its top, bottom, right and left hand edges. The working advance of all the rams round its circumference in each push forward must, therefore, be very carefully watched and regulated; and this duty has to be entrusted to a reliable and intelligent foreman of the mining gang. On horizontal or vertical curves one edge has to be advanced in excess of the opposite edge by an exact amount, the other two opposite edges on a diameter at right angles to these being advanced equally. The foreman receives his instructions with regard to these differences from the surveyors, and the practical means whereby he carries them out are long wooden rods scaled to feet and fractions of a foot. With these he measures from gauge marks on the already finished part of the tunnel up to similar marks on the hinder part of the shield. It is not necessary that each 20-inch push should be mathematically exact: a continuous rectification goes on from step to step, the error in one push being neutralized by an allowance made in the next. The surveyors reproduce underground in plan a line that has been surveyed with precision on the street surface overhead, the proper levels being also set out with all possible exactitude. As an example of the precision attainable, may be quoted the drive between Westbourne Park and the Marble Arch stations,

1288 yards long, under the management of Mr. Arthur Woodroffe Manton, engineer to the contractor, Mr. John Price, in which the two ends met with an error of only ⅝ inch. Such accuracy can be attained only with surveying instruments in the best condition, and by the exercise of the most scrupulous care in the survey and in the driving of the shield. If the two ends meet within an inch or so, there is little trouble or expense in the special fitting and jointing of the rings at the junction.

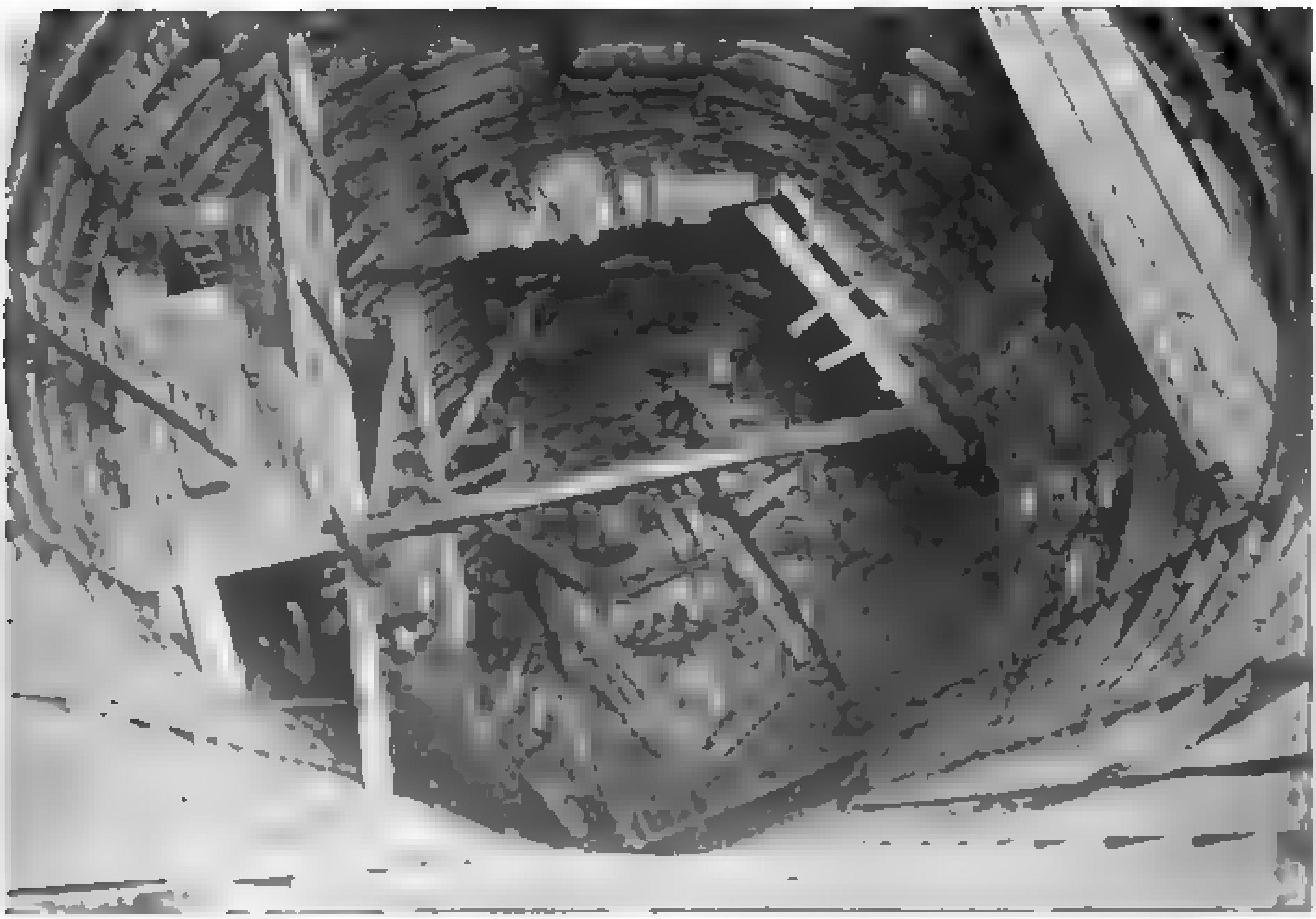


FIG. 134.—Central London Railway Station Shaft, looking down during construction.

10. At each station a vertical shaft is excavated from the surface, and from the base of this are driven in each direction the large-sized station tunnel, and from this again forwards and backwards the two track tunnels. The vertical shaft is usually 25 feet in diameter, and it is lined with iron segments, larger and of thicker scantlings, but of the same general pattern, as is used in the tunnels. Outside the rings of iron segments the space is filled in with hydraulic lime as in the tunnel. The lining is built in downwards, each ring being inserted as soon as the excavation has proceeded to a depth convenient for the work. Fig. 134 gives a photographic view of one of these shafts

during construction. Fig. 135 gives a similar view of the working head of a tunnel with the shield in place; and Fig. 136 is a drawing giving section, rear and front elevations, of a shield with 12 feet 8 inches diameter cutting edge. For these and other illustrations, as well as for much interesting information, the author is indebted to Mr. W. Noble Twelvetrees, the writer of an excellent series of articles in *Feilden's Magazine*, and to the editor of that journal, as also to the British Thomson-Houston Company, who were the contractors for all

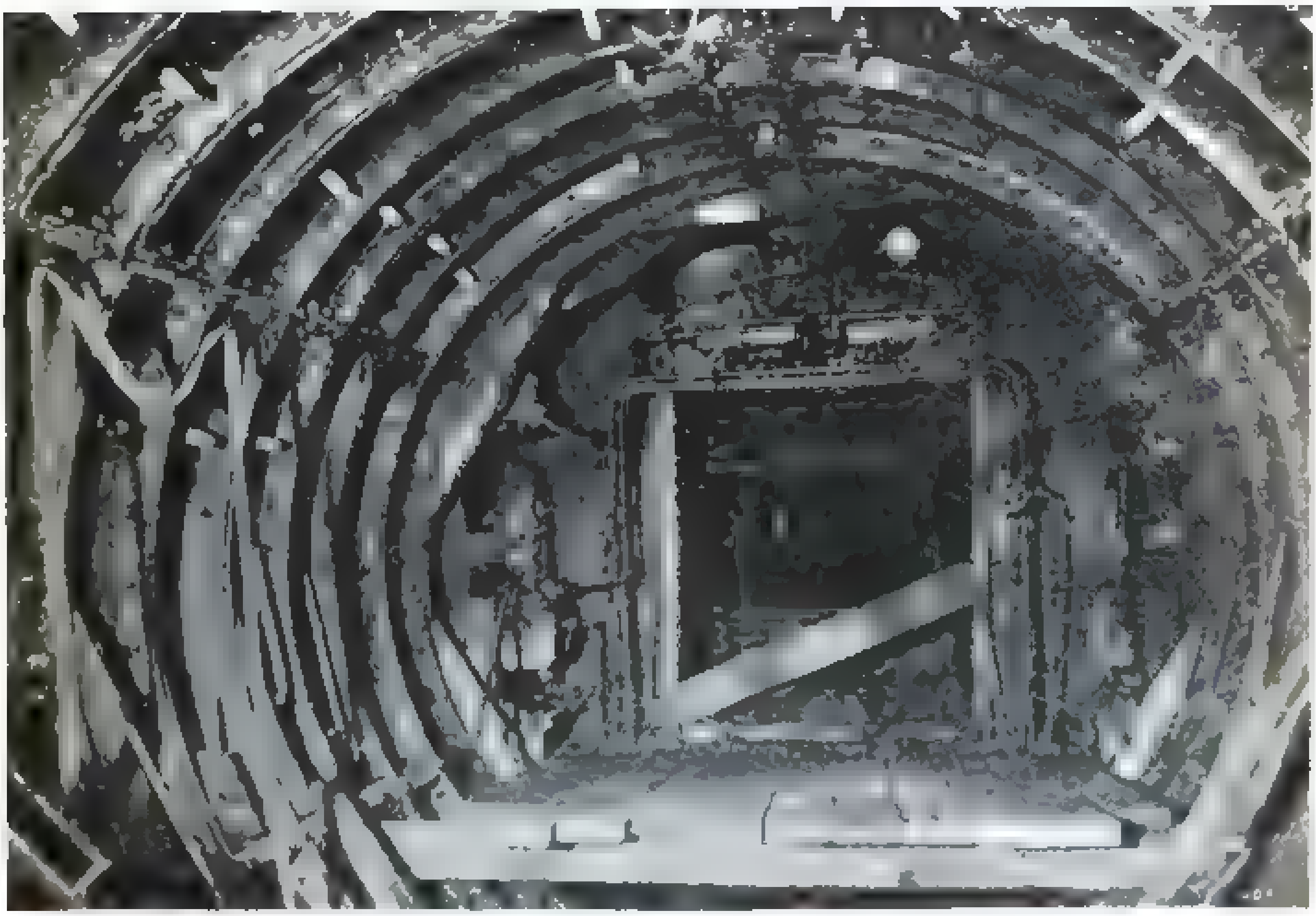


FIG. 135.—Working Head of Tunnel with Greathead Shield.

the electrical work. Mr. John Price, contractor, and the engineers, Mr. Francis Fox, Messrs. Galbraith, and Sir J. Szlumper, have also very kindly supplied much technical information, diagrams, and working drawings of the new tubes now being constructed and referred to in detail below.

All the machinery used in driving the Central London tube was worked by compressed air at about 80 lbs. per square inch pressure. Hydraulic plunger pumps, with 1-inch plungers and driven direct from 7-inch air cylinders, supplied high-pressure water to the 7-inch rams on the shield. This gives, with six rams, a cutting thrust of

between 300 and 400 tons on the shield, and, as the air pressure can be raised to 100 lbs., over 400 tons can, when needed, be employed on the tunnel shields, and three times as much upon the station shields with 22 rams.

Altogether 31 shields and 3000 men were employed on the Central London Railway tunnels and shafts. About half a million cubic yards were excavated, and about one-tenth of a million tons of cast-iron segments were built in with some 3000 tons of bolts.

11. At six of the stations a single shaft, 30 feet in diameter, each accommodating two large and one small lift, is sufficient. At five other stations, two shafts, each 23 feet in diameter, are required, and here four lifts of the smaller size are employed. At the Post Office there are three shafts, and at the Bank five shafts, at each of which stations five lifts are kept busy. The smaller size of lift-cage has 117 square feet of area, while the larger has 145 square feet; but those at the Bank have 250 square feet. In all there are 24 shafts and 48 lifts in the 6½ miles of double line. The depth is greatest at Notting Hill, where it is 91½ feet, and least at Shepherd's Bush and Westbourne Park, where it is 41 feet. The very moderate speed of 180 feet per minute is used for the lift-travel, as the majority of the population in London are not yet accustomed to the use of high-speed lifts. Each car is lifted by four ⅞-inch hard steel wire ropes of 22 tons breaking strength, or 88 tons combined strength. The weight of the fully loaded cage never exceeds 19 tons. The rope has a hemp core, with six strands, each of 19 wires, laid round it. Each cage is counter-weighted independently. The lifting power is furnished by two enclosed 4-pole shunt-wound direct-current motors. The shaft of each motor drives a duplex right and left hand worm, the one worm driving directly the winding drum-shaft while the other does so through an idler shaft and spur gear. The two motors, lying at opposite ends of the drum and on opposite sides of the bedplate of the machine, rotate in opposite directions; and this, along with the duplex arrangement of worms, when well fitted, balances the stresses arising from worm end-thrust and from mass-accelerations of the rotating armatures. The winding drum is automatically braked by powerful spring-blocks when the current from any cause is interrupted, and toggle-joint clamps on the cage grip the vertical guide-posts with a force of 22 tons whenever the speed of descent rises above a specified limit, the control being by a centrifugal rotating governor mounted under the floor of the cage and driven by a pulley rotating in proportion to the speed of the cage. The lift motors in each station are ranged in series, the effect of which is to distribute in a certain manner, among all the motors running at one instant, the whole work being done, this being so because the motors are shunt wound. Each cage is so balanced that work is done on it only during its ascent. During its

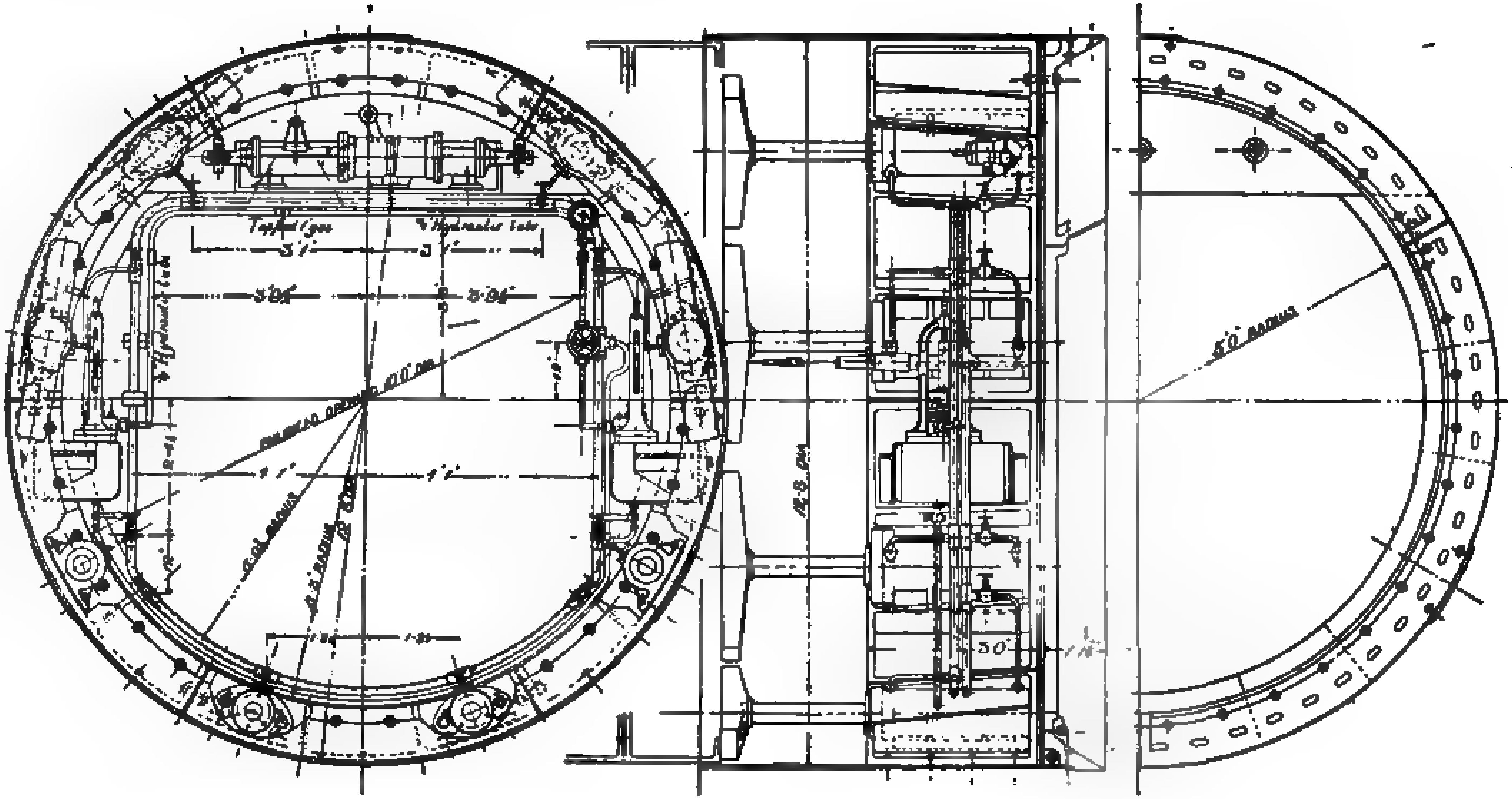


FIG. 186.—Greathead Shield with 12-feet 8-inch Cutting Edge. Front and Rear Elevations and Horizontal Section.

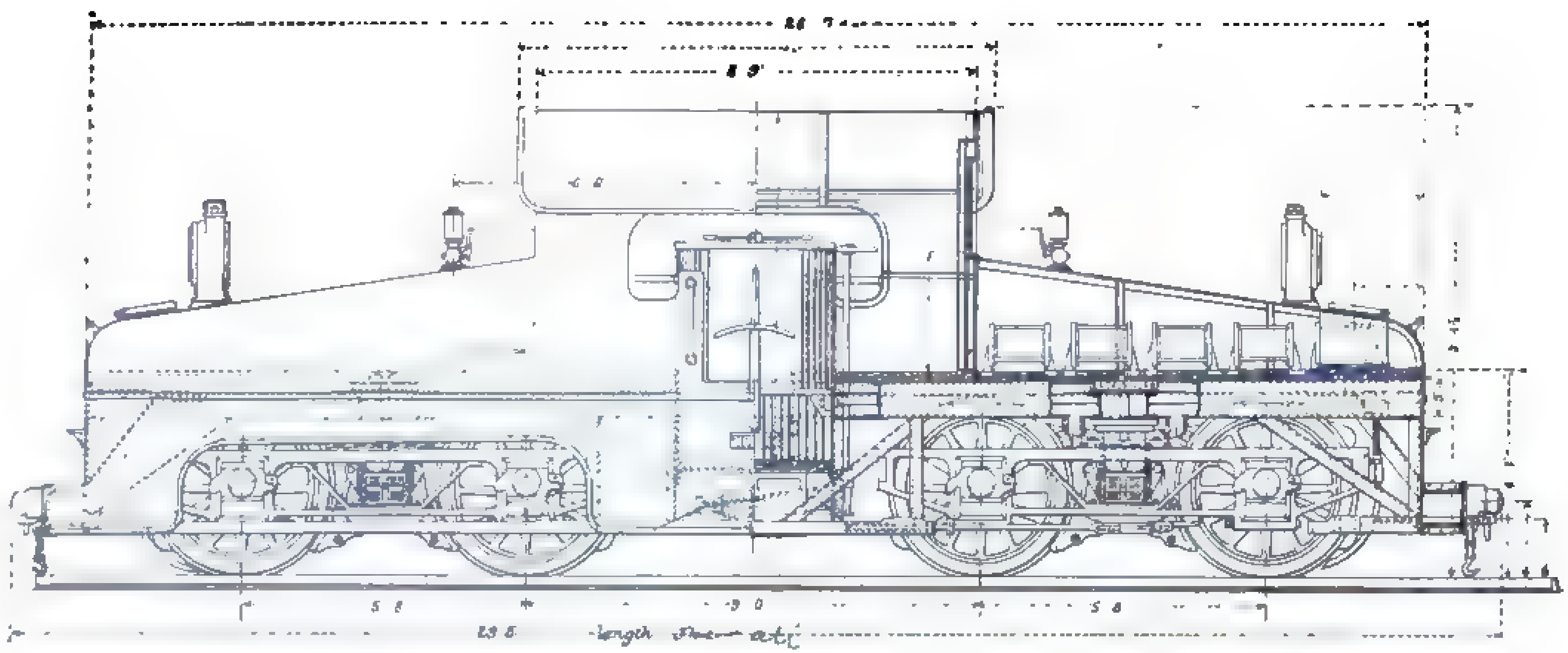


FIG. 137.—Electric Gearless Locomotive—Elevation

descent it drives its motor as a dynamo, which thus supplies current that helps in the lifting of the simultaneously ascending cages.

12. The Bank station, where there are five large lifts, is built under the causeway in the centre of the circus formed by the meeting of eight streets, and the exits from the station are by subways and short stairs up to the side pavements. The subway forms an oval circuit round the lifts and ticket office, from which oval branches lead off to the staircases. Another branch subway leads straight to the terminal station of the City and Waterloo electric railway. These subways afford convenient means of crossing the crowded thoroughfare, especially for ladies and others not able to make their way through the closely packed carriage traffic.

13. The trains on the Central London Railway were at first drawn by electric gearless locomotives. Fig. 137 gives a side elevation, and Fig. 138 a cross section through the swivel pin of one of the bogie-trucks, of this locomotive. The weight of the locomotive is 43 tons. It is carried on two bogie-trucks, and there is a 117-horse-power motor on each axle, or four motors per locomotive. These motors have their armatures directly keyed on the wheel-axle, and, therefore, both axle-boxes and motor field-magnets are fixed to the truck-frame without springs. The cab alone is spring-borne, and only a quarter of the load on each axle is cushioned by springs. Owing to the hammering and vibration caused by this arrangement, it was abandoned in favour first of geared locomotives and eventually of motor-cars. The geared locomotives are 31 tons in weight, of which two-thirds is spring-borne. The rated horse-power of each of the four motors is 150, and the gear ratio is 3·3 to 1, while the wheel tyres have 3 feet diameter. Figs. 139, 140 and 141 give the elevation, plan, and cross-section of the bogie-truck of this locomotive. The running is much smoother than with the ungeared machine; but, as the vibration from the tunnel was still greatly complained of in the houses and shops along the route, the system of trains made up of motor and trailer cars has been definitely adopted. In 1901 a prolonged investigation of these vibrations was made by three gentlemen nominated by the Board of Trade, Mr. Mallock being the member of the committee who made the actual measurements by help of a special momometer

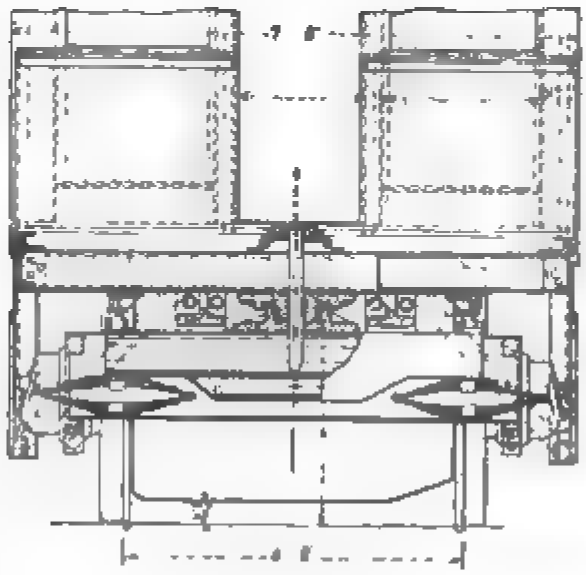


FIG. 138.—Gearless Locomotive—Cross Section.

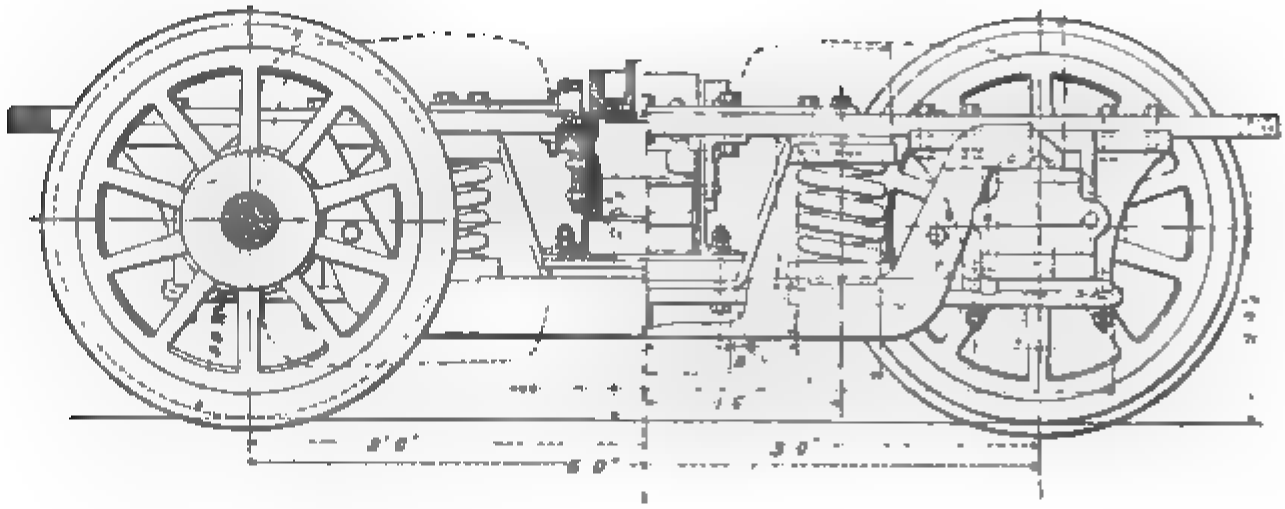


FIG. 139.—Electric Geared Locomotive Truck—Side Elevation.

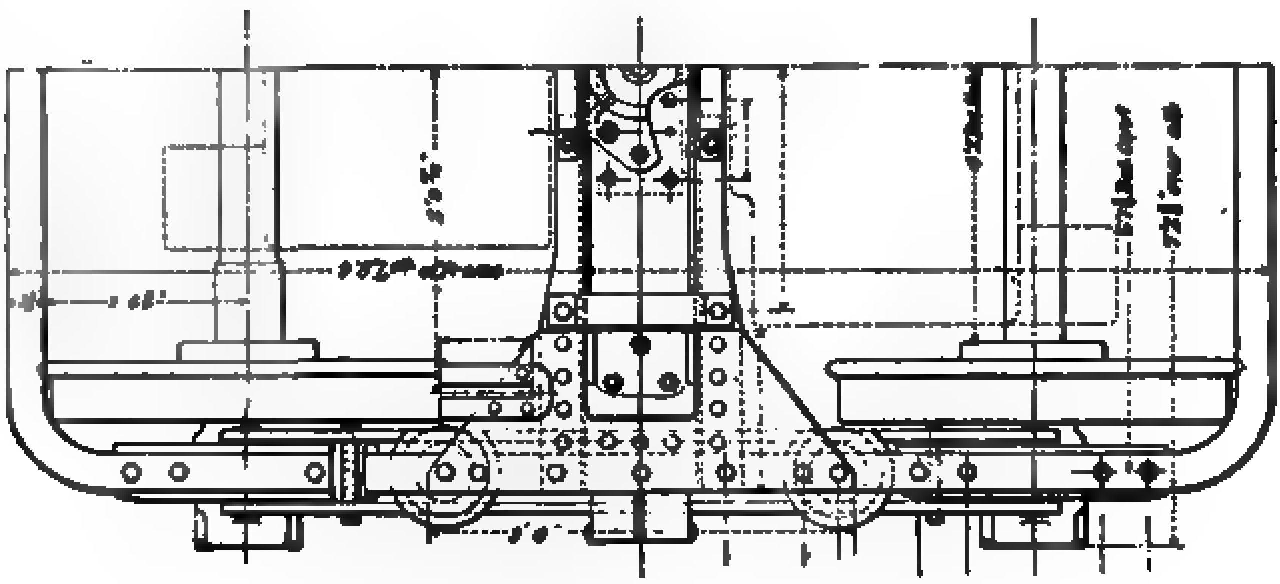


FIG. 140.—Electric Geared Locomotive Truck—Plan.

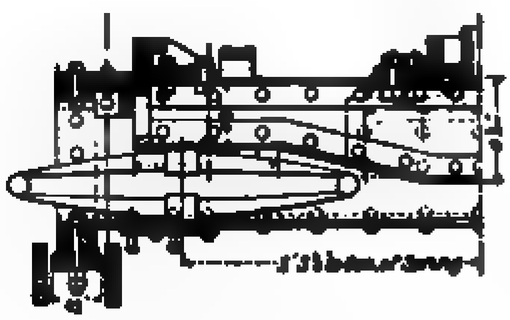


FIG. 141.—Electric Geared Locomotive Truck—Cross Section

Fig. 142.—Motor-coach for Seven-coach Train.

designed by himself. The results were of considerable scientific and engineering interest, but there is not space here for a *résumé* of them. They may be studied in the Report and its Appendix, which were issued as blue-books.*

14. Each train is now made up of seven cars, the front and last car being motor-cars, while the intermediate five are for passengers only. Fig. 142 shows an outside view of a motor-car. Fig 143 is a section of the 125 horse-power motor used, while Fig. 144 gives its characteristic curves. The weight of the motor is nearly 2 tons, of which almost half is spring-borne. The wheels are 34 inches in diameter, and the gear ratio 4 to 1. A motor drives each axle of the front bogie-truck of the car, so that four motors drive each train, giving in all 500 nominal horse-power.

15. Figs. 145, 146, and 147 give three detail views of the motor-truck, which, along with its two motors, weighs 8 tons, and whose wheel-base is 6 feet. Two equalizer beams, whose outline is chiefly dotted in Fig. 145, distribute the load between the two axles, and the truck-frame is supported at each side by this beam through the intermediation of two strong spiral springs. This underframe supports the bolster by two transverse elliptical plate springs. The car body rests upon the truck at the centre of the bolster only. The brake-blocks act on the outsides of the wheels alone. The horn-plates are hydraulically compressed steel castings and are riveted to the top frame. The current collector is a sliding shoe of chilled cast-iron. It is shown in Fig. 148. It is slung in the centre-line of the truck by the two oblique links, shown in the drawing, from a timber plate bolted to the transom, that is, the double cross-beam which forms the guide-box for the bolster. The face of this shoe is 10 inches parallel to the rail and 21 inches transversely. This great width is needed for passing the points and crossings. The shoe is pressed against the third-rail conductor by its own weight only without springs. The current is led from the shoe by a short length of flexible coupled to a well-covered cable taken up through an iron pipe-shield to the terminal of the switch-board in the driver's cab.

Each motor-car weighs, inclusive of 2½ tons of passengers, 25½ tons, of which 8½ tons is thrown on each driving axle. Of this 8½ tons, 6½ are spring-borne. The brakes are operated by air-pressure, and a two-cylinder air-compressor, motor-driven, is carried on each car. At 300 revolutions per minute this compressor compresses 14 cubic feet of atmospheric air per minute. It is governed automatically by a cut-out switch controlled by the air-pressure itself, cutting off current

* See B.T. blue-books, Cd 951 and Cd 975–1902, entitled "Central London Railway (Vibration)."

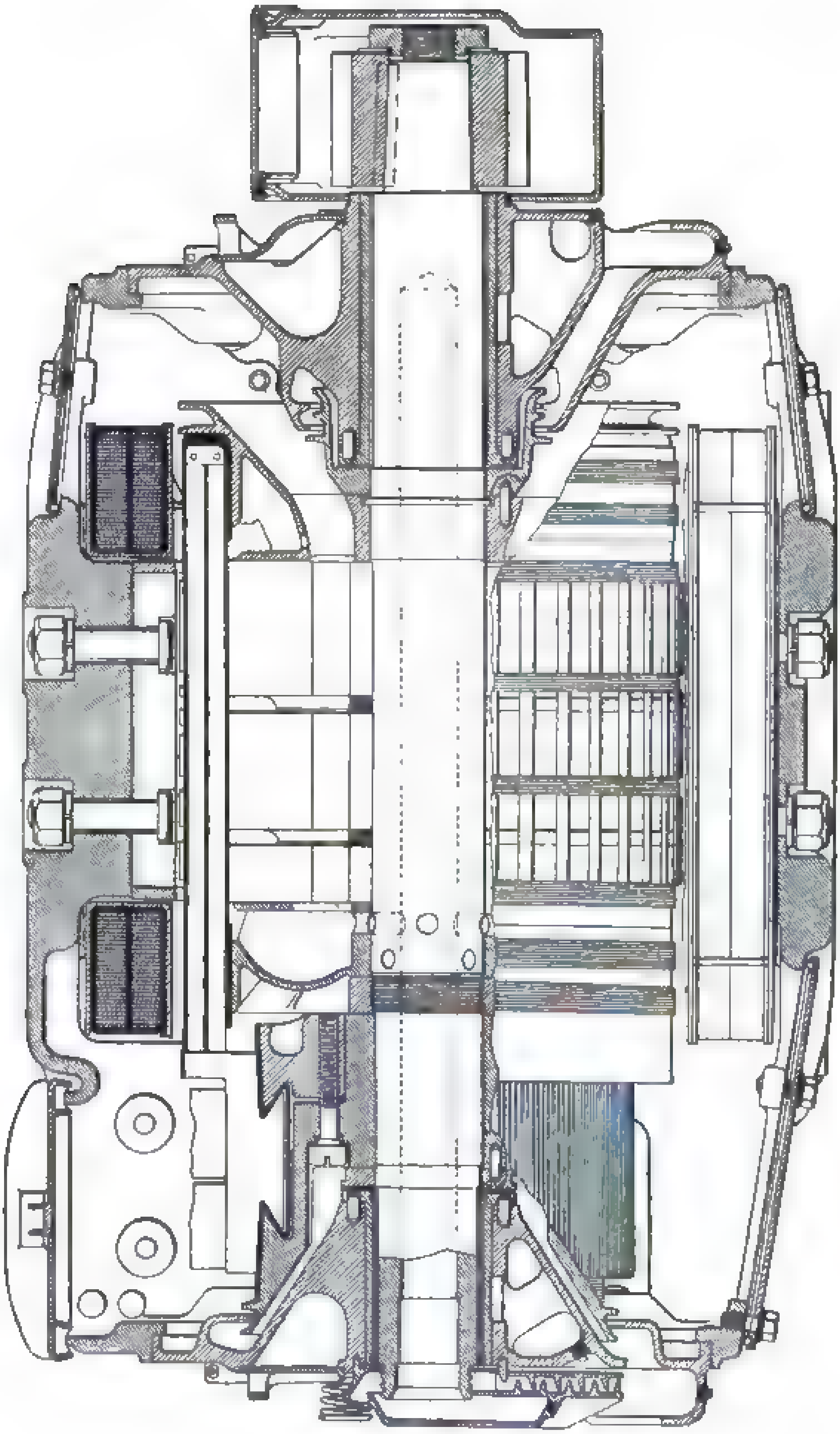


Fig. 143.—125-horse-power Electric Railway Motor.

when the pressure reaches 90 lbs. per square inch, and switching the current on again when it falls to 80 lbs. per square inch.

16. The driver's cab is built throughout of steel, and is partitioned off from the passenger compartment by a steel wall covered on both sides with incombustible material. The two motors at the two ends of the train can be, and are, controlled from either end. A nine-wire control cable passes from end to end of the train through an iron tube on the roof, the different sections over the seven cars being coupled by a spring plug-coupling. A small lighting cable passes similarly along the roof.

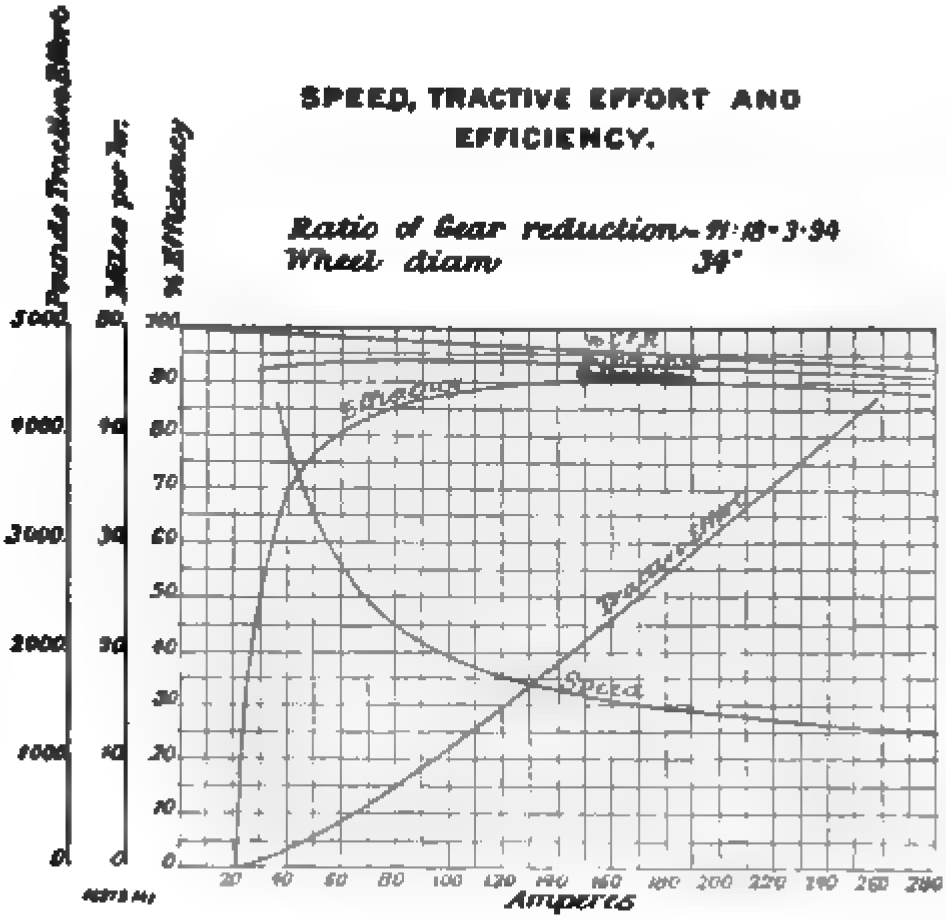


Fig. 144.—Performance Curves of 125-horse-power Motor.

The trailer bogie-truck of the motor-car has 5 feet wheel-base, and the length between the trucks, centre to centre, is 29 feet. The trailer-truck carries a collector-shoe of the same pattern as that on the motor-truck, and in permanent electrical connection with this latter.

The controller in each motor-cab consists of a number of switches, or "contactors," as they are called in this system. These contactors are fixed in a wooden framework on one side-wall of the cab. Under them on the floor are placed the rheostats giving the starting resistances. The ensemble of the contactors constitute a series-parallel controller governing the electrical driving action in the usual method. All the switches are electrically operated by a relay current coming

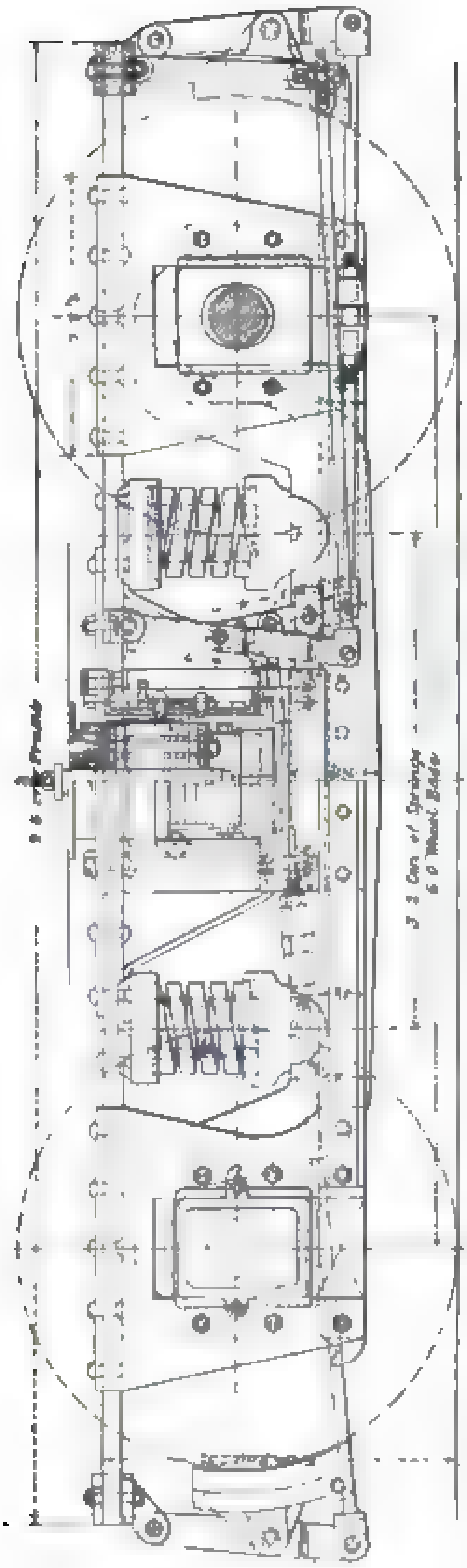


Fig. 145.—Motor-coach Bogie Truck with Equalizer Beams—Elevation.

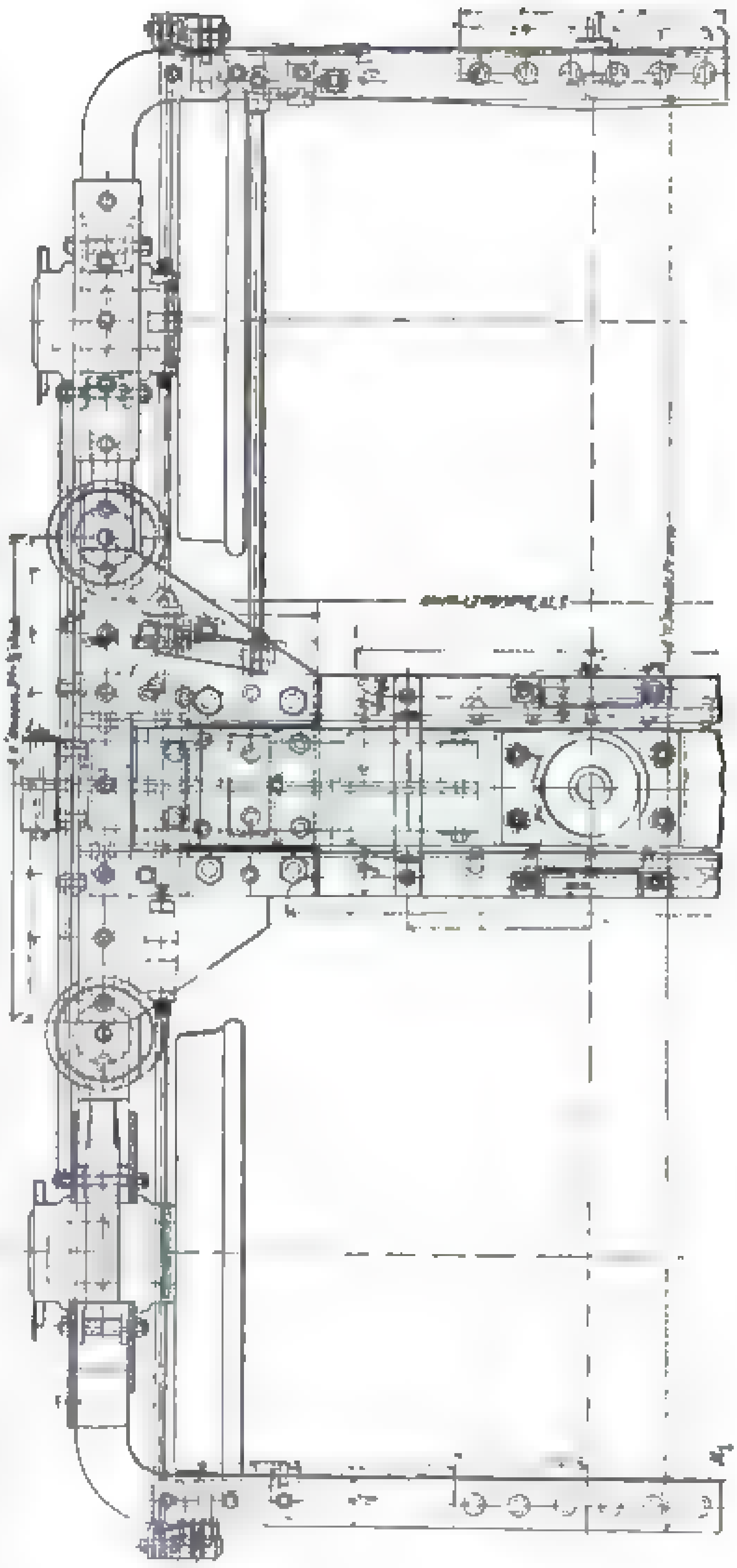


Fig. 146.—Motor-coach Bogie Truck with Equalizer Beams—Plan.

from a single small-sized master controller, which is, so to speak, an image, on a small scale and traversed by weak currents only, of the whole group of switches. The driver handles the master controller only. The current through the control-cable along the whole length of the train is that (or rather those, because it is a nine-wire cable performing nine distinct functions) from the master controller, and the effects in the two cabs at the two extreme ends of the train are identical.

This system is called the Sprague system of multiple control; but the Central London Railway installation does not show it much developed, as there are on each train only two pairs of motors to be similarly controlled.

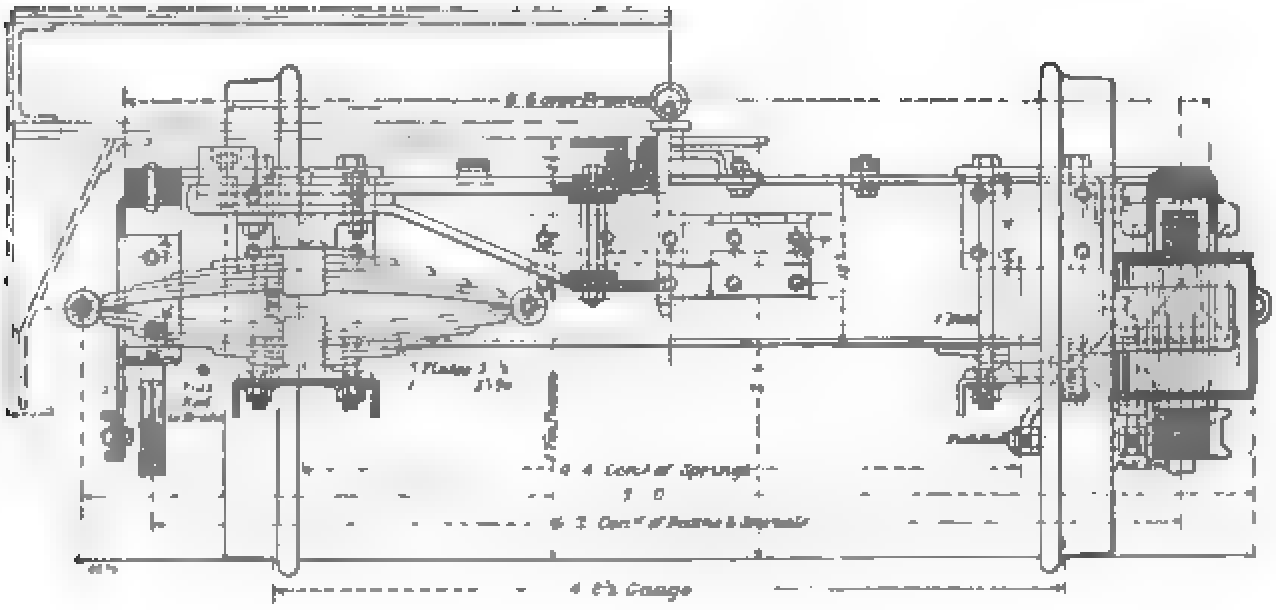


FIG. 147.—Motor-coach Bogie Truck with Equalizer Beams—Cross-sections.

17. The records of current consumption do not show that the change from the gearless locomotive to the motor-car driving has resulted in any greater mechanical efficiency. With the gearless locomotives the consumption was from 42 to 48 watt-hours per ton-mile. With the geared locomotives it seemed to vary from 40 to 58. Measurements on the motor-car trains gave from 41 to 48. It is to be noted, however, that the latter tests were taken with trains some 40 per cent. lighter than in the other tests, and that with heavier load the motor-car consumption per ton-mile is probably materially less than the above. The motor-car arrangement, however, gives rather more seating accommodation per ton of train. It gives 2·85 seats per ton, whereas with gearless locomotives it was 2·44, and with geared locomotives 2·57 per ton. Fig. 149 is a typical volts-and-ampères diagram for a 105-ton motor-car train running from the West to the City. On this run the consumption per ton-mile

was 45·8. The stop at stations varies from 30 to 45 seconds. The average acceleration in starting is from $\frac{6}{10}$ to $\frac{2}{3}$ mile per hour per second, or somewhat less than 1 foot per second per second. The speed goes up to from 18 to 20 miles per hour, and the average speed, inclusive of stoppages, is 14 miles per hour. Fig. 150 is a chart of an average run of just under half a mile. The dotted curve

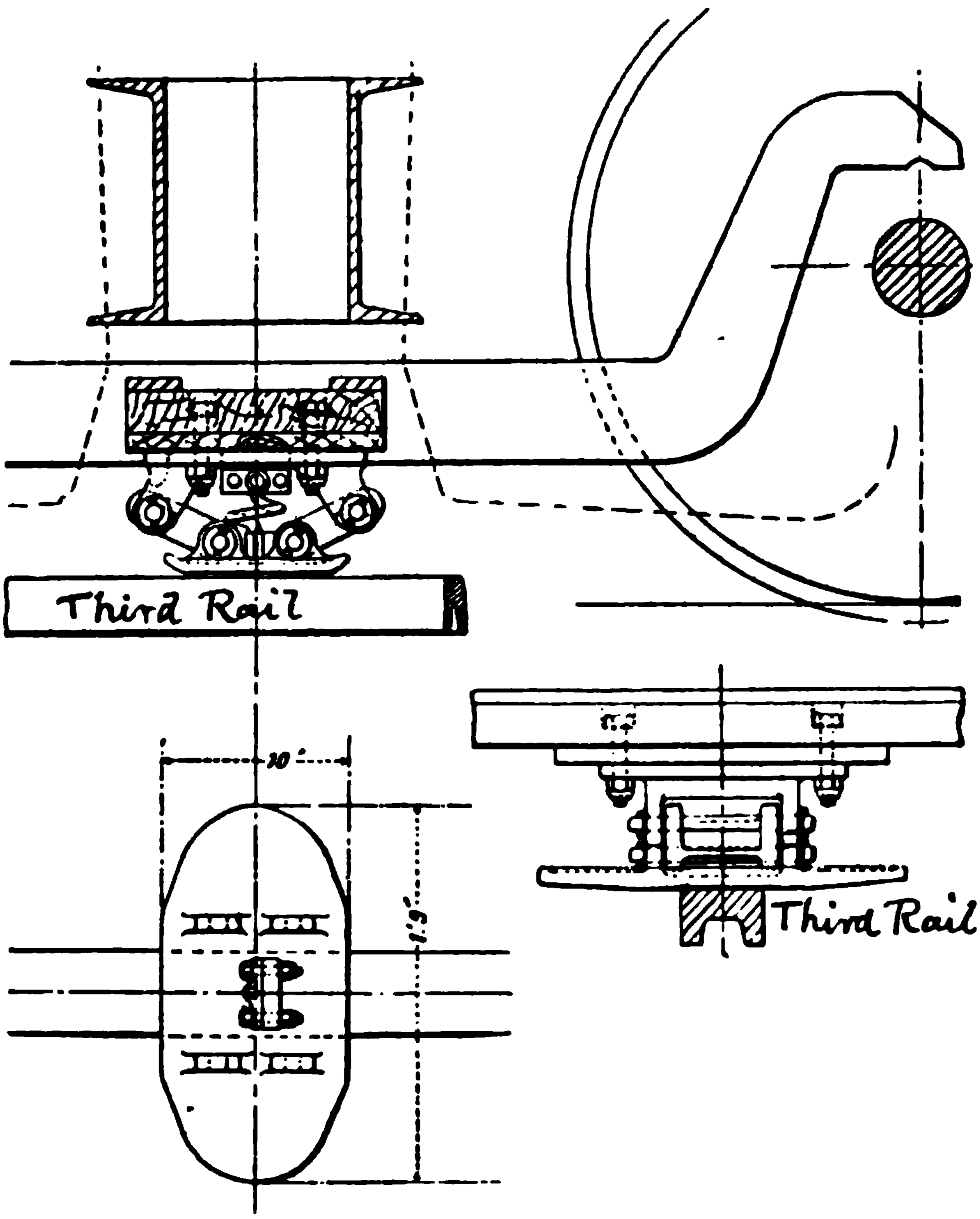


FIG. 148.—Collector Sliding-shoe for Third-rail.

of acceleration is seen to rise from over $\frac{1}{2}$ to less than $1\frac{1}{2}$ foot per second per second in the course of between 20 and 25 seconds, and then during the next 15 seconds to fall to $\frac{1}{2}$ foot per second per second. This includes the acceleration due to the down-grade giving a fall of 8 feet in 240 feet, as seen in the profile sketched at the right-hand end of the diagram. At about 40 seconds from the start the current, which has started up from 400 to above 800 ampères when

the controller has shifted the motors from series to parallel working, is cut off; the acceleration drops suddenly to below zero; and the speed begins to fall slowly, the train "coasting" along without either electric or gravity driving power. In the diagram the rise of the speed curve looks nearly uniform, but it is actually concave upwards for over 20 seconds and convex upwards during the next like period; its maximum slope being double those at the beginning and at the end of its rise. The "space," or distance run, curve has a similar anticlinal shape throughout its length; and it should be noted that the length of the down-grade is the space travelled during the rise of the acceleration curve to its peak. At 65 seconds, or 1600 feet distance, climbing the up-grade into the station begins, this producing extra retardation and extra downward slope of the speed curve. The brakes are applied at between 90 and 100 seconds, or about 120 or 130 feet from the stop, and throughout the 10 or 12 seconds occupied by the stop the retardation is 2 feet per second per second, or almost $1\frac{3}{8}$ mile per hour per second. This retardation is sufficient to stop the train from $13\frac{1}{2}$ miles per hour speed in 10 seconds, or from $16\frac{1}{2}$ miles per hour in 12 seconds.

18. The following is Mr. H. F. Parshall's estimate of how the energy given to the train is spent. The figures are in watt-hours per ton-mile. Fourteen watt-hours of energy are obtained from gravity by the 8-foot fall on the down-grade, and 43 are supplied electrically, making a total of 57 watt-hours per ton-mile.

Train resistance while current is on	19
Up-gradient, useful braking effect	14
Train resistance during stopping	1
Brakes	11
Motor iron and copper losses	2
Rheostat losses	10
Total	57

19. It has already been mentioned that the 550-volt direct current is supplied to the third-rail conductor from four sub-stations at Notting Hill Gate, Marble Arch, Bond Street, and the Post Office. The Bond Street station was a subsequent addition to the original design. There is also a transforming and converting plant at the central power station. Three hundred and thirty kilowatt transformers are used, giving 330 volts on the secondaries at 25 cycles frequency. These transformers give 98 per cent. efficiency. The rotary converters are rated at 900 kilowatt, each being fed by three transformers. Each sub-station contains two converters and seven transformers. The converters are capable of 90 per cent. overload for

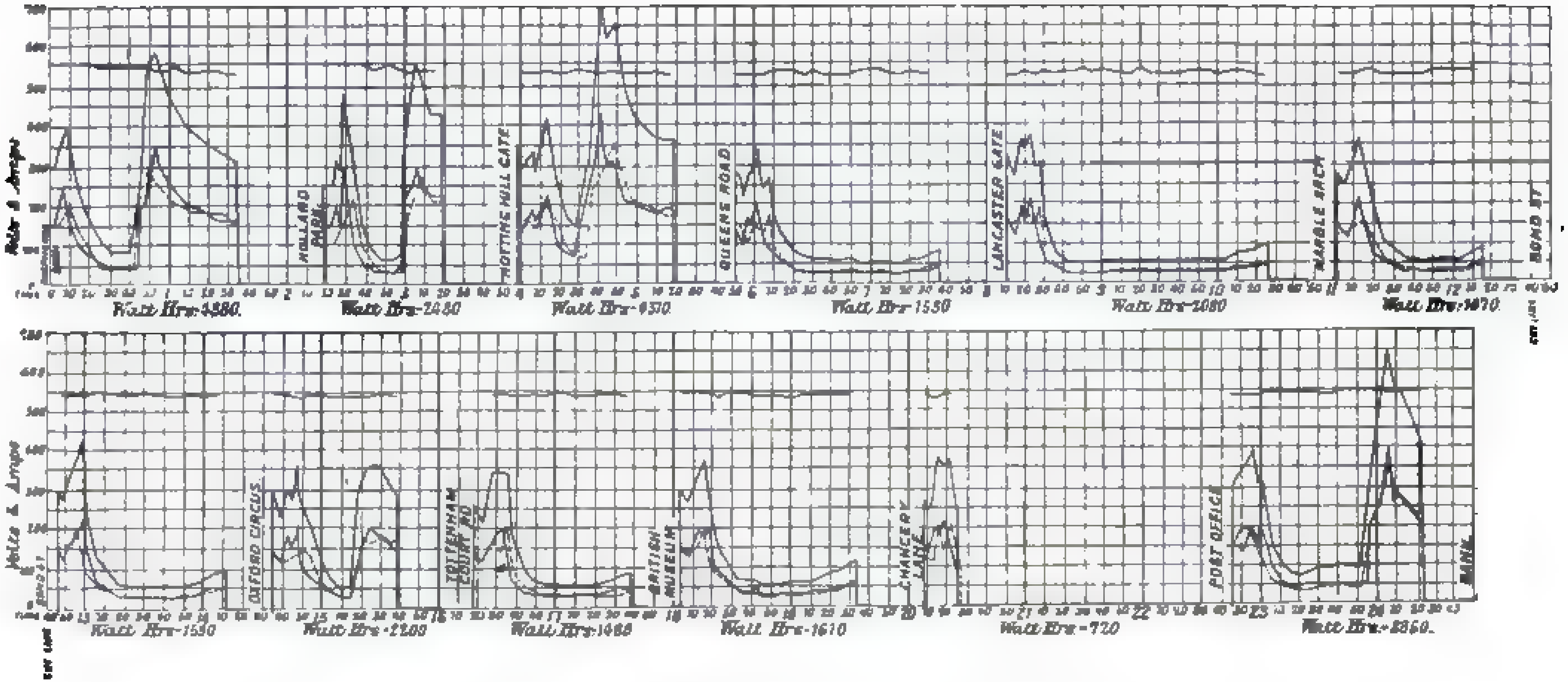


Fig. 149.—Energy-consumption Diagrams on Central London Railway.

a few minutes, and of 50 per cent. overload for prolonged runs. Their normal efficiency is 95 per cent. They are 12-pole machines, with 7 feet diameter of armature, and run at 250 revolutions per minute. A section and an elevation of one of them are seen in Figs. 151 and 152. The pole-pieces are laminated and the armature is slotted, while the commutator has 576 segments. The field is compound wound, the strength of the series field being regulated by a special rheostat. The normal winding gives 550 volts at zero and

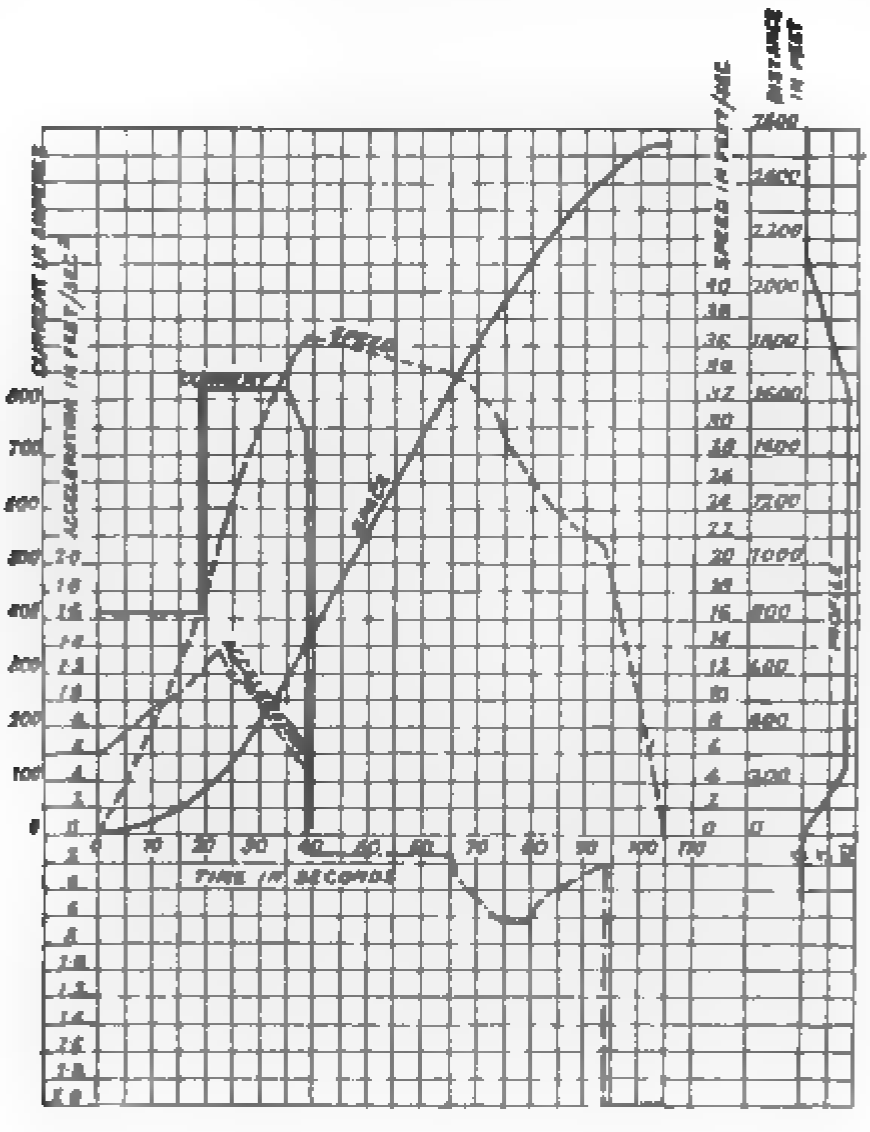


Fig. 150.—Acceleration, Speed, and Distance Diagrams on Central London Railway.

full load with 330 between the A.C. collector rings, and a slightly higher voltage at intermediate loads, and lower voltage on overloads. The converter is connected to the 550-volt busbars by a 3-pole Parshall quick-break switch, and the machine is synchronized on the low-tension side. The third-rail conductor is sectioned at each feeding point, and, in case a sub-station is shut down, is bridged over at the section insulator. The daily peak load is about the same in each sub-station, namely about 1200 kilowatts. It lasts over three hours,

and during this time the current output oscillates rapidly between about 1400 and over 2800 ampères, the mean being about 2200. The efficiency of the total conversion from high-tension A.C. to low-tension D.C. is 89 per cent. The third-rail feeders take about three-quarters of the total energy generated, the remainder being spent on lighting, station lifts, ventilating fan, and machine-driving in the central station.

20. The 6½ miles of double tunnel are ventilated by in-draught at the passenger stations, induced by a large suction fan erected in the yard of the central station at Shepherd's Bush. This fan is 20 feet in diameter, and it creates a vacuum of 5 to 6 inches water gauge. It is driven by a high-tension 3-phase induction motor. This system of ventilation necessitates the closing of the western end of the tunnel against atmospheric pressure, so that the trains from the central station yard have to pass in and out of the tunnel through an air-lock consisting of an inclined siding of length greater than that of a train.

21. The central station contains six main 3-phase generators built by the British Thomson-Houston Company, and driven by horizontal cross-compound Corliss-valve jet-condensing engines by E. P. Allis and Company, of Milwaukee. The generators are of 850 kilowatt power at 100 ampères output and unit power-factor. The external stationary armature has 16 feet diameter, while the diameter of the internal rotating 32-pole field is 12 feet. The speed is 93¾ revolutions per minute for 25 per second frequency. The soft-iron stampings of the armature are 0·014 inch thick, and there are 192 slots, being 2 slots for each phase per pole. The field-coils are wound with copper strip, and the normal excitation is 110 ampères by 125 volts. The efficiency, making allowance for excitation energy, is 95 per cent. The extreme overload capacity with power-factor unity is 1160 kilowatts. Fig. 153 gives the characteristic output curve with unit power-factor.

22. The engines have cylinders of 24 and 46 inches in diameter by 48 inches stroke, and are supplied with 150 lbs. per square inch steam, while the jet-condensers give 26 inches vacuum. The cylinders have no steam jackets. The steam is reheated between the high and low pressure cylinders by fresh boiler steam. Their maximum indicated horse-power is 1900, while their most efficient working rate is 1250 indicated horse-power. Their best mechanical efficiency is 94 per cent., and best steam consumption 13½ lbs. per indicated horse-power hour. They are governed to within 2 per cent. variation of speed, and an emergency governor closes the throttle-valve entirely at 105 revolutions per minute. The fly-wheel, which is 18 feet in diameter and of 50 tons weight, may run up to 125 revolutions per minute without risk of fracture.

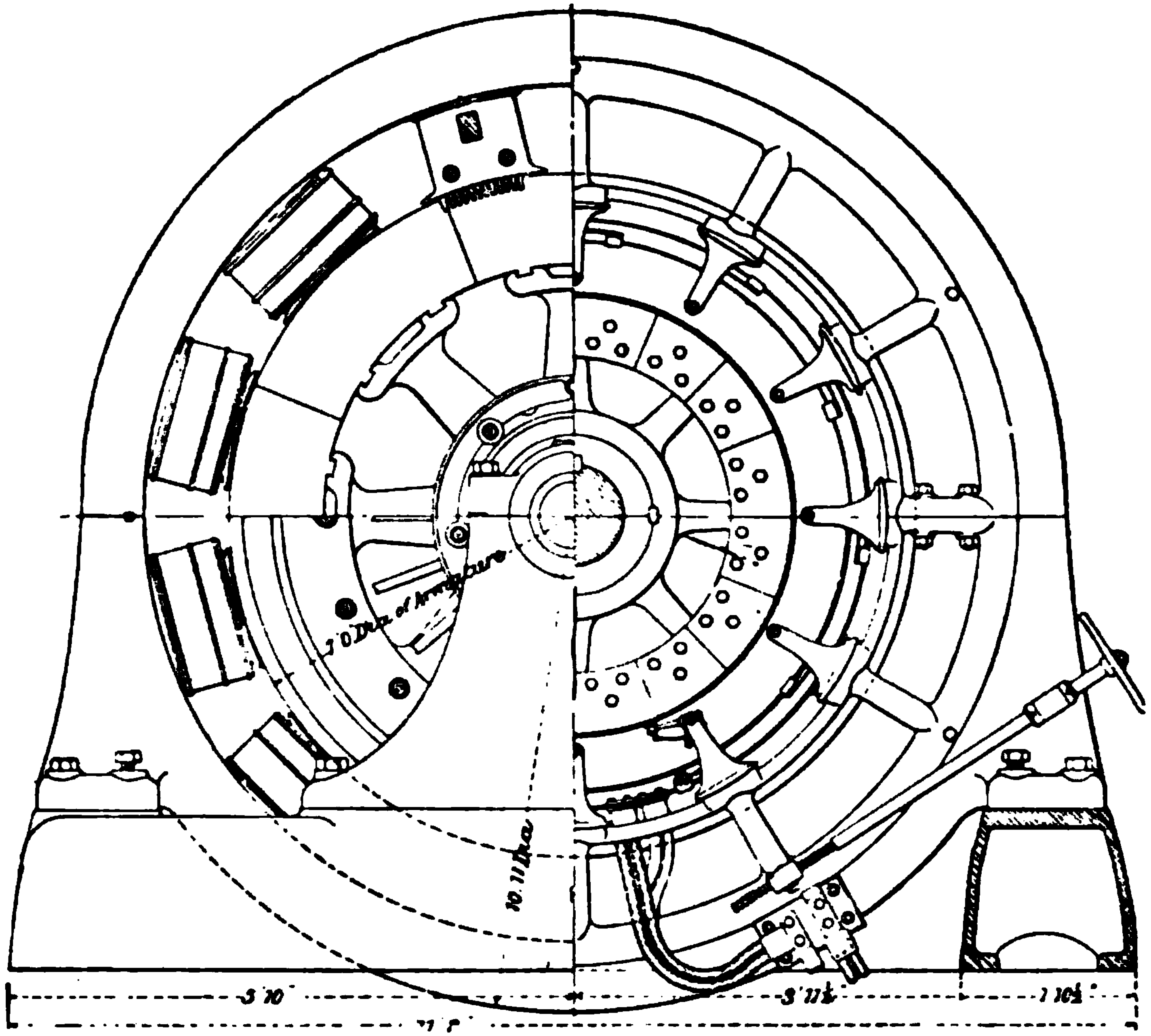


FIG. 151.—900-kilowatt Sub-station Rotary Converter—End Elevation.

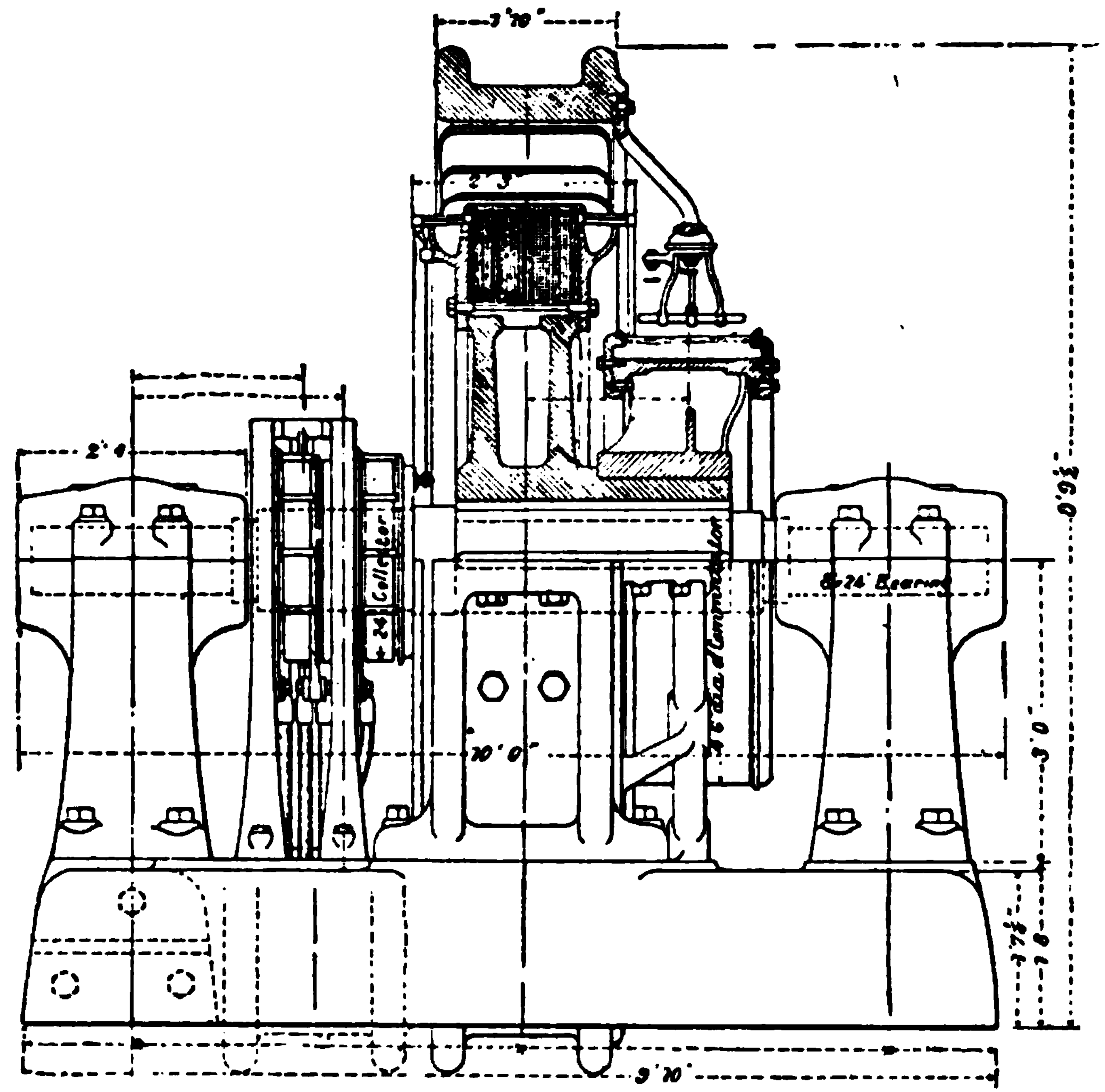


FIG. 152.—900-kilowatt Sub-station Rotary Converter—Longitudinal Section.

The combined efficiency of engine and dynamo together, as tested, is 90½ per cent. at full, and 85½ at two-thirds, load. The full normal peak load can be taken by four engines and generators, but five units do the work more economically. The exciting sets consist each of a 50-kilowatt, 6-pole, 125-volt dynamo, and a vertical compound tandem engine running at 400 revolutions per minute. Recently there have been added two other sets driven by Belliss and Morcum engines, which do all the lighting of this central station and car sheds. New surface condensers have also been laid down, two independent plants drawing from a common exhaust pipe which serves all the main engines. These are worked by Edwards air-pumps, and three new cooling-towers have been built for these condensing plants. It is proposed to erect a fourth cooling-tower, the

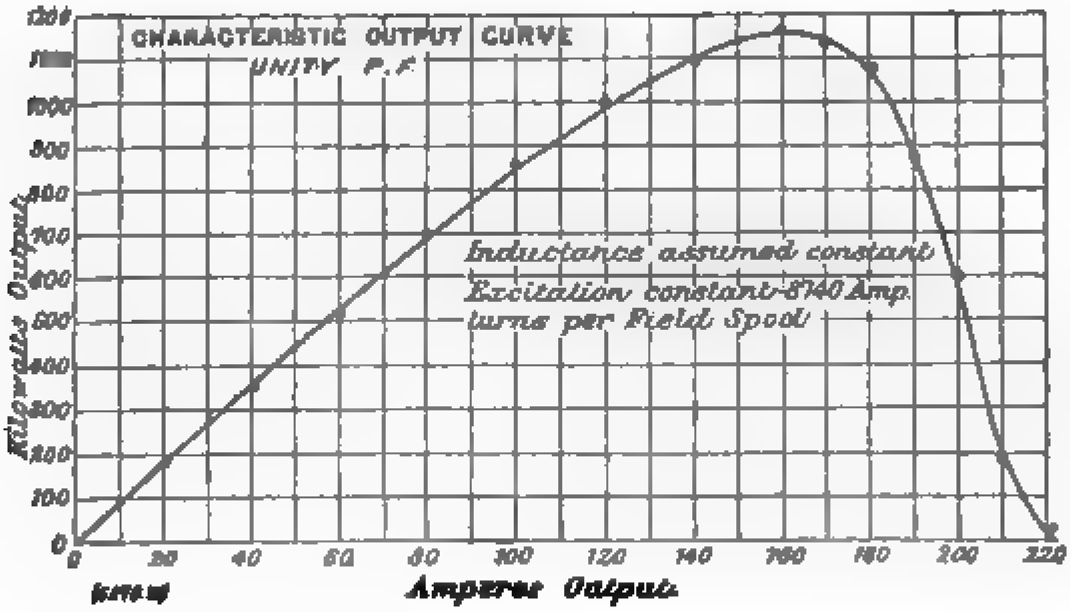


FIG. 158.—Characteristic Curve of Generator at Shepherd's Bush Power Station.

demands for power created by the ever-increasing traffic being somewhat difficult to meet. The draught through the cooling-towers is created by fans in the basement driven by 35-horse-power Belliss and Morcom engines.

23. The engines are supplied from twenty Babcock and Wilcox water-tube boilers with Green's economizers. The boiler tubes are 4 inches diameter and 18 feet long, and each boiler has 3580 square feet heating surface and 90 square feet grate area. Each is rated at 12,000 lbs. per hour steaming capacity at 160 lbs. per square-inch pressure. Vicars' mechanical stokers were originally fitted to all the boilers, but these are not well suited to the coal now used, and all but one boiler are now hand-stoked. Small Welsh steam-coal is at present being used. The coal is tipped into hoppers, from which it is carried by a chain-and-bucket conveyor to an overhead

bunker of 1500 tons capacity and which is 28 feet wide and extends the whole length of the boiler-house. The ashes are raked into steel tubs running on a tramway in a tunnel stretching in front of each row of boilers immediately underneath floor-level.

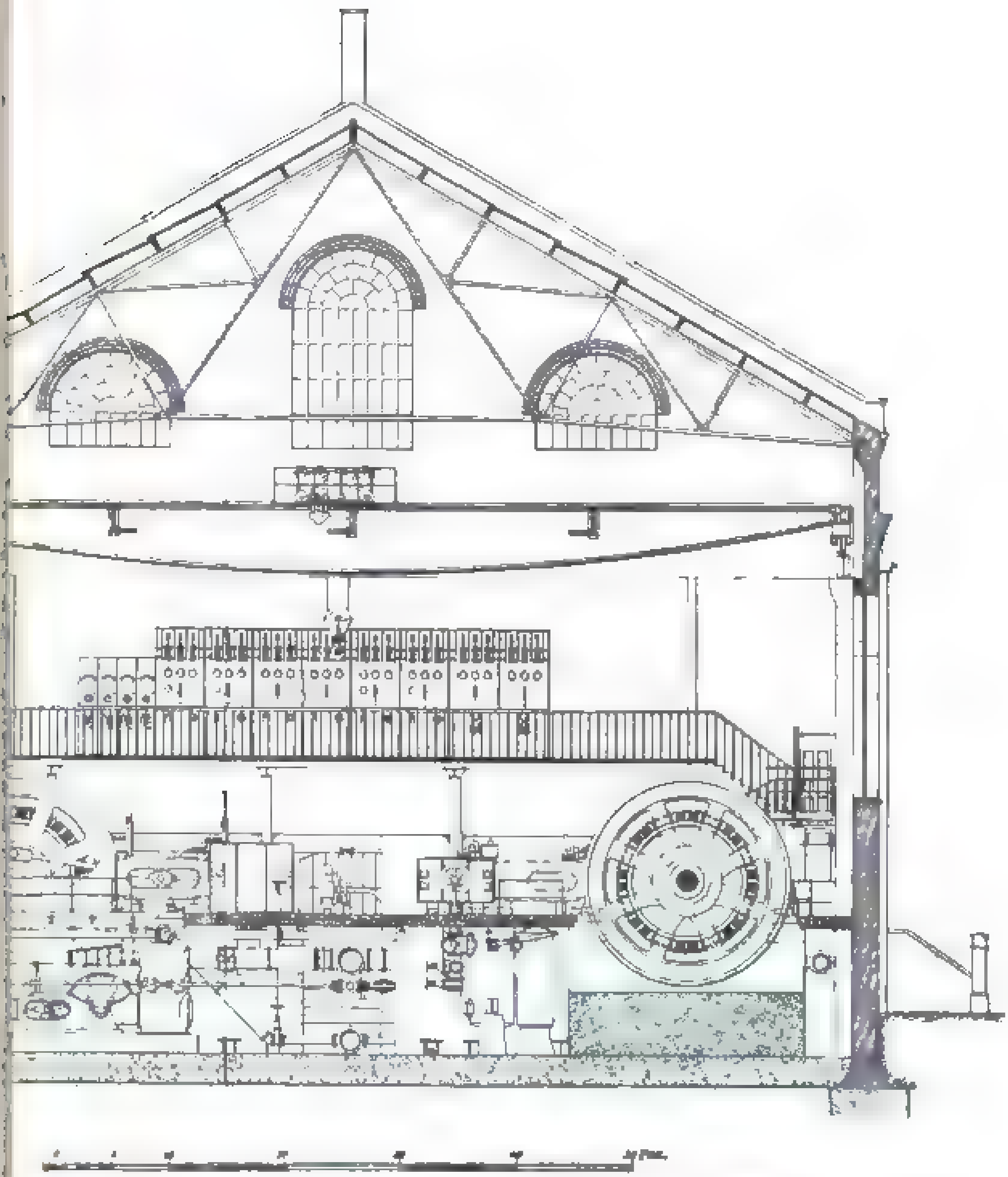
24. Figs. 154 and 155 explain the general arrangement of this power house so clearly that further description is unnecessary. Fig. 154 is the section through boiler and engine houses, while Fig. 155 is a plan of the latter only. All the steam and exhaust piping is carried under the floor of the engine and dynamo house, and all pumps are also placed in this basement. The main switchboard stretches across the end of the engine-house where the exciters lie, and is raised on a gallery which gives a complete and commanding view of the whole plant above floor-level.

25. Having now described in detail the most recent of the three completed deep-level railways, a short notice of the similar lines now being built, and expected to be in operation at an early date, may be given. In the first place, the routes may be examined with the help of the map in Fig. 156.

The first of these to be commenced was the "Baker Street and Waterloo." Parliamentary authorization has been obtained to extend this to Westbourne Grove, west of the G.W.R. Paddington terminus; but no work west of Baker Street has yet been done. The Baker Street station is just north of the Metropolitan underground station, and from here the line runs eastward under the south end of Regent's Park as far as Park Crescent, and here turns, with very easy curvature, southwards along Portland Place, and then down Regent Street, bending eastwards again through Piccadilly Circus. At the north end of the Haymarket it passes over the Brompton tube mentioned below, and then runs south under the Haymarket, bending west to pass the south side of Trafalgar Square, and down Northumberland Avenue. Here it dips to pass under the river just above the Charing Cross railway bridge, whence it passes under Waterloo Station. This is as far as it is being built at present, but the company has powers to extend along Westminster Bridge Road and London Road to the Elephant and Castle, where there will be an intercommunication station connecting it with the City and South London tube. At Waterloo it communicates with the City and Waterloo tube.

The length from Waterloo Station to Baker Street Station is $2\frac{3}{4}$ miles. The southern extension to Elephant and Castle will be $\frac{7}{8}$ mile long; and the western extension to Westbourne Grove, $1\frac{1}{4}$ mile.

26. The second north-and-south line traversing London does not pass under the river, but starts close to it on the northern Embankment, just east of the railway bridge. At this place there will be intercommunicating passages connecting this electric railway terminus



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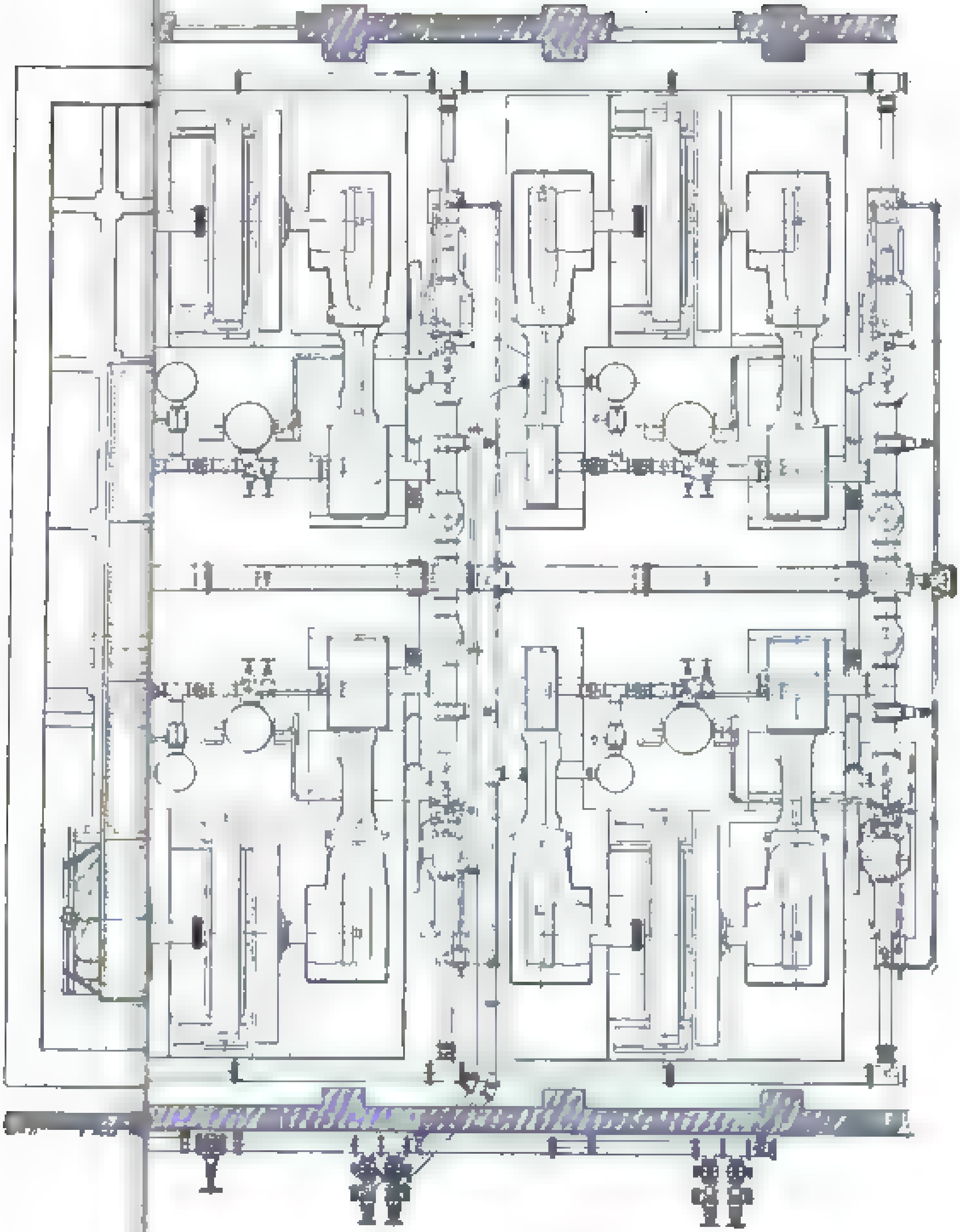

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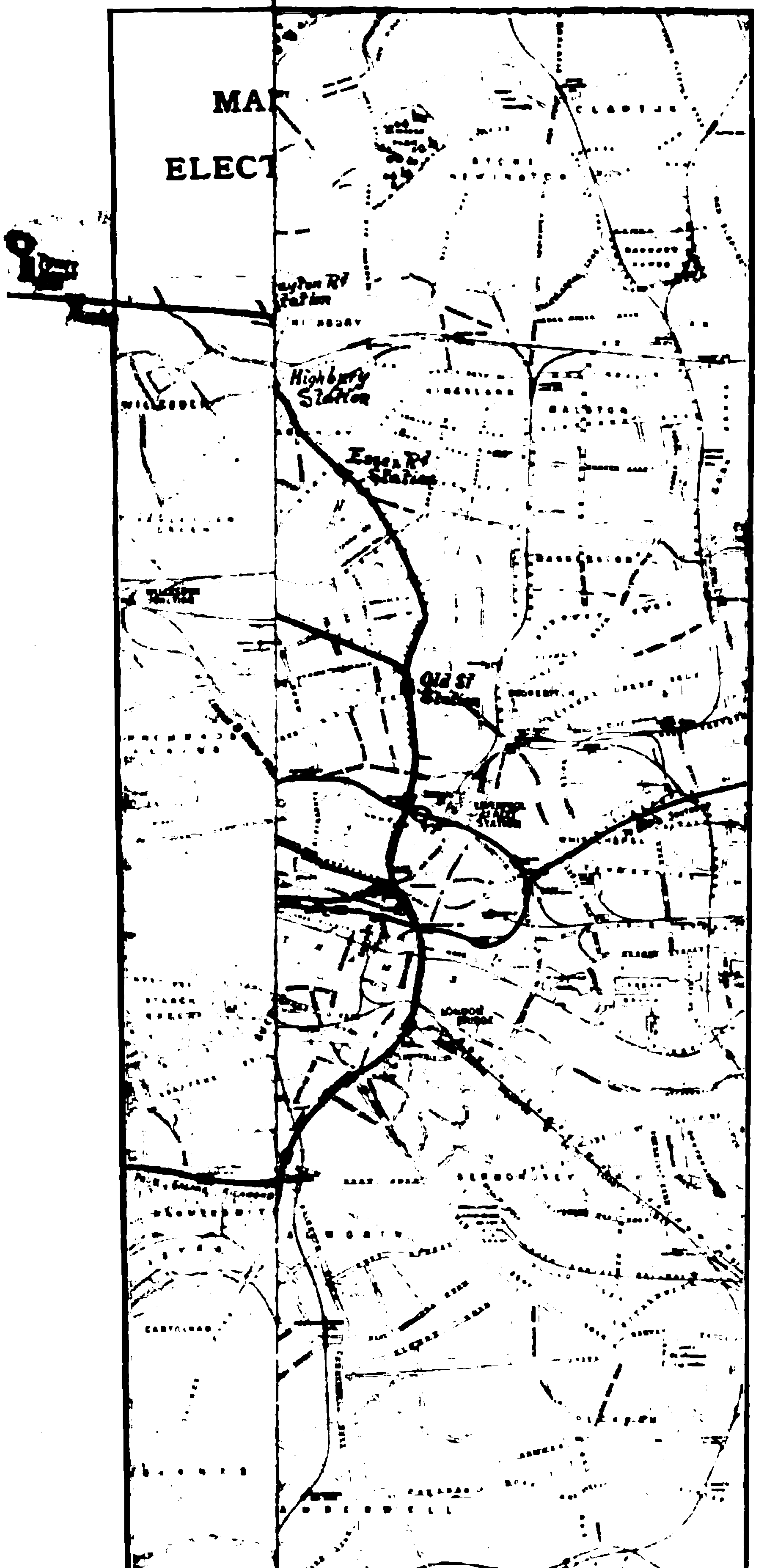

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with the platforms of the Metropolitan District Railway, Charing Cross Station, the electrification of which is now being completed, and also with the deep-level station of the Waterloo–Baker Street electric railway above mentioned. The railway starting here is called the "Charing Cross, Euston, and Hampstead" line. From this terminus it runs north under the Strand, westwards along King William Street, under St. Martin's Church, and northwards under the line of Charing Cross Road and Tottenham Court Road, passing under Oxford Street and Euston Road. Here it sweeps north-east along Drummond Street and the entrance to Euston L. & N.W. Railway station, again bending sharply to the north along Seymour Street to the great junction of the Camden Town, Kentish Town, and Chalk Farm Roads. Here the deep-level tube branches. The shorter branch runs straight north to the Archway Tavern at the foot of Highgate Hill. The other branch follows the line of Haverstock Hill and Hampstead High Street, passes underneath Hampstead Heath and Golder's Hill, and issues to the surface at Golder's Green. At present it is not being built further than this, but powers have been taken to extend it to Hendon—a prolongation of about 2 miles length. This extension will run on the surface.

The following are the names of the stations on this route, and the distances between them in yards:—Charing Cross: 377: Cranbourne Street: 500: Oxford Street: 646: Tottenham Court Road: 520: Euston Road: 628: Euston: 800: Mornington Crescent (junction of Hampstead Road and High Street): 845: Camden Town: 917: Chalk Farm: 1193: Belsize: 1183: Heath Street, Hampstead: 1736: North End: 1074: Golder's Green.

From the junction at the south end of the Kentish Town Road northwards the distances are:—Camden Town: 616: Castle Road: 710: Kentish Town: 883: Tufnell Park: 1078: Highgate.

From Charing Cross to Camden Town the total route length is 4316 yards; from Camden Town to Golder's Green, 6103 yards; and from Camden Town to Highgate, 3287 yards. The three branches total to 7·8 miles route length.

27. In passing under the Strand, this line is at 70 feet depth from street-surface to rail-level. At Cranbourne Street the depth is 86 feet. Here staircases furnish intercommunication with the platforms of the Brompton and Piccadilly tube, which is here 98 feet below surface. From here the line rises at a gradient of 1 in 300, and passes under Oxford Street at 86 feet depth. Here, again, an interchange deep-level station is formed by staircases leading to the platforms of the Central London tube.

The line continues to rise northwards at 1 in 120 gradient, and passes the Euston Road at 88 feet below street-level. Just north of Euston Road the tunnel passes through sand and gravel, and to keep

the water out an air-tight shield and air-lock had to be used. The 1 in 120 grade continues to the Camden Town Station, and here the depth is 62 feet; but at this junction, there being four tubes to join in two pairs, and the width of roadway not being sufficient for a double-track junction at one level, the junction is effected at two levels, 62 and 51 feet below the street, the one being almost immediately above the other. It should be explained that the right to bore at whatever depth under any parts outside the street limits requires to be purchased from the owners of the surface land, and to avoid this purchase some additional expense in construction is economical. The crossing and junction of the one pair of tubes over the other occasions extra expense in building of platforms and staircases; but, on the other hand, there is less "third" and running rail electrical complication in two simple junctions at two levels instead of a double junction at one level, and also no material increase of cost in boring the tunnels is incurred. On the contrary, it is a saving in expense, trouble, and anxiety to avoid the very large excavation and its lining with strong iron "segments," necessary for the double junction, which would involve the use of an extra large size of shield and special strengthening and stiffening design of the iron lining. One advantage of burrowing through the clay is that it is as easy and as cheap to bore along a twisted line as along a straight one, the twist only giving the surveyors a little extra opportunity to display their skill in keeping to the specified alignment.

From this junction the one branch climbs to Highgate at a gradient of 1 in 80, and ends at the Archway Tavern 71 feet under ground.

The Hampstead branch climbs the Haverstock Hill at 1 in 60 gradient, but is, nevertheless, 195 feet below street-surface at the Heath Street station. Its depth below ground in passing under Hampstead Heath is much greater than this. It is still 24 feet under ground at the foot of Golder's Hill, and a quarter of a mile further north it runs into daylight.

The engineers for these lines are Mr. Francis Fox and Messrs. Galbraith, and the contractor Mr. John Price.

28. The third great deep-level line now nearing completion is the "Brompton and Piccadilly." At present this is built as far as South Kensington only; but work is being carried on to extend it to Earl's Court and to Kensington High Street.

At South Kensington Station there is to be intercommunication by lifts with the platforms of the Metropolitan District station. It is also proposed to bore a subway up the line of Exhibition Road to the Albert Hall.

From the South Kensington Station the deep-level route runs into and along the line of Brompton Road to join Knightsbridge at the

north end of Sloane Street. Thence it runs to Hyde Park Corner, and along Piccadilly to Piccadilly Circus. From here it runs by Leicester Square along Long Acre to the north end of the new King's Way in High Holborn. Here it joins with the Great Northern and Strand line.

The stations are: South Kensington, Brompton Road (depth, 60 feet), Sloane Street (depth, 62 feet), Hyde Park Corner (depth, 66 feet), Down Street (depth, 60 feet), Dover Street (depth, 80 feet), Piccadilly Circus (depth, 108 feet), Cranbourne Street (depth, 98 feet), Covent Garden (depth, 113 feet), and Holborn. The length from Holborn to South Kensington is 3 miles. The extensions to Earl's Court and High Street, Kensington, will add 1½ miles to this length.

At Piccadilly Circus this tube has an exchange station with the Baker Street and Waterloo, and another at Cranbourne Street with the Charing Cross, Euston and Hampstead line.

In this railway the stations are placed on rises as in the Central London. The approach to each station has the up-gradient of 1 in 66; while the acceleration down-grades out of the stations are 1 in 33. The approach to Piccadilly Circus Station is special—only 1 in 85—on account of the crossing here with the Baker Street–Waterloo line.

The sharpest curves are of 5 chains radius, four such curves occurring west of Brompton Station, and six east of Covent Garden, while there are also two curves of 7 and 8 chains at Sloane Street.

This railway at its west end runs out on the surface and joins the Metropolitan District Railway, in conjunction with which it is to be worked. It is, therefore, worked on the same system as described in next chapter for this and the Metropolitan, namely, with "third" and "fourth" insulated out and return conductor-rails, placed respectively 3 inches and 1½ inch higher in level than the running-rails. The running-rails are 95 lbs. per yard, 2¾ inches width of tread by 5¾ inches deep. The conductor-rails are 80 lbs. per yard, 2¾ inches width of tread by 4¼ inches depth.

29. The fourth line is called the "Great Northern and Strand." It runs from Finsbury Park through King's Cross to the Strand. The southern terminus is on the Aldwych Crescent, forming part of the London County Council Strand Improvement scheme. It runs to Holborn under the new King's Way. Here it joins the Brompton and Piccadilly line, and from this point runs up Southampton Row. The stations are: Aldwych, Holborn, Russell Square, King's Cross; Barnsbury, Holloway, and Finsbury Park. The route length from Finsbury Park to King's Cross is 2½ miles; from King's Cross to Holborn, 1 mile; and thence to Aldwych, under ½ a mile.

30. A fifth route is named the "Great Northern and City." It is seen on the map running from Finsbury to Moorgate Street, with intermediate stations at Drayton Park, Highbury, Essex Road, and

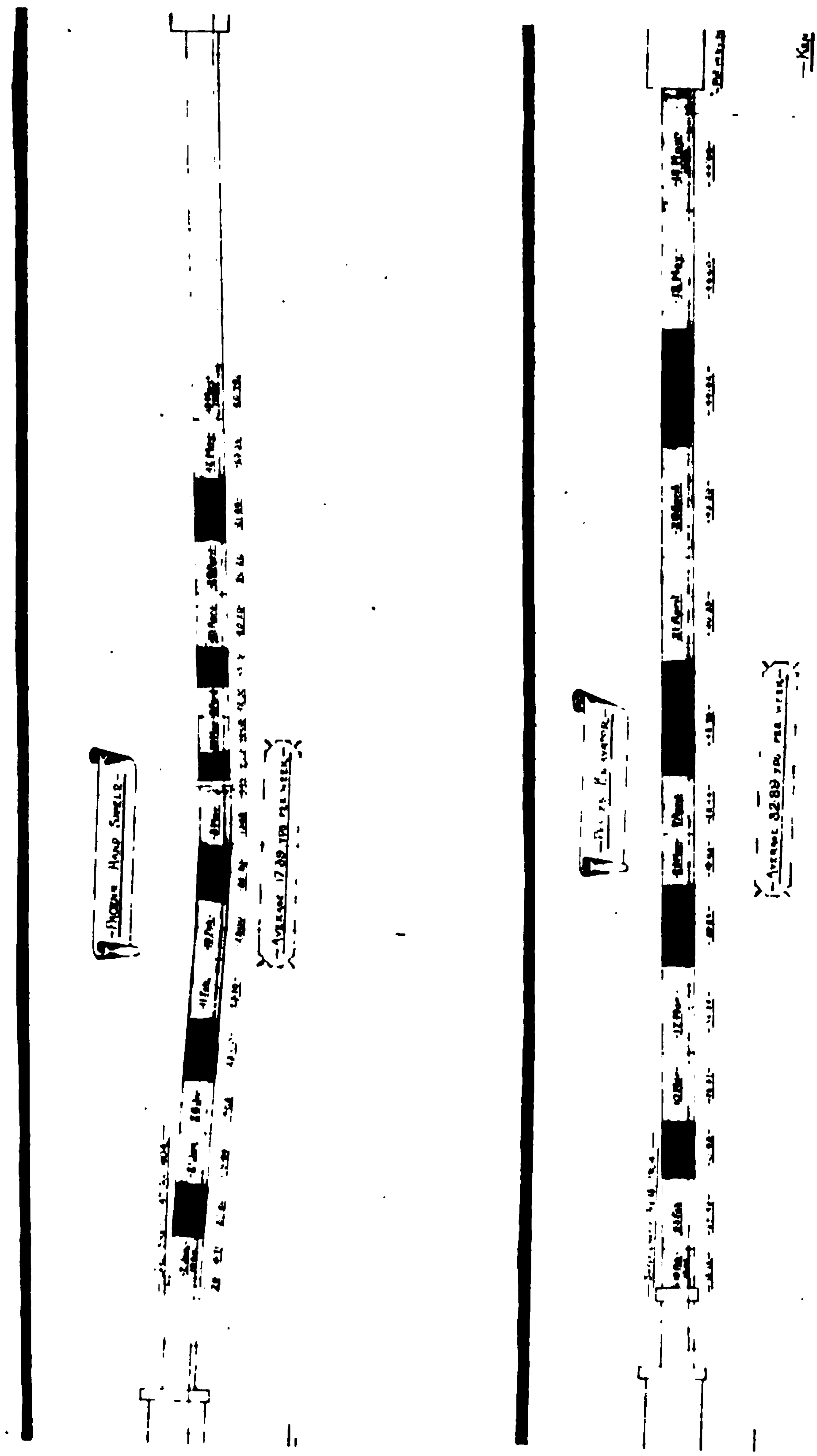


FIG. 157.—Comparison of Work done by Price's Excavator and ordinary Hand Shield.

Old Street. From Old Street to Moorgate Street its route coincides with that of the "City and South London" tube. A service of trains has been running for some time on this route. It is about $3\frac{1}{2}$ miles long.

31. The map (Fig. 156) also shows clearly the route of the City and Waterloo tube. It runs along Queen Victoria Street to Blackfriars Bridge, crosses under the Thames immediately above this bridge, and proceeds along Stamford Street into Waterloo Station. There are no intermediate stations. Unfortunately, this line has not been furnished with lifts to take the passengers down to it and bring them up again, and the long and steep entrance and exit passages are so tedious as to greatly diminish the utility of the line. Its length is nearly $1\frac{1}{2}$ miles.

32. The map also gives the route of the City and South London deep-level railway. Starting from the east end of Clapham Common, it runs along Clapham Road and Kennington Park Road to the Elephant and Castle; thence through the Borough to London Bridge, where it passes under the Thames, and up King William Street to the Bank. This was the original extent of the line, and many years passed before a prolongation was decided on. As mentioned previously, this was the first deep-level railway constructed. Eventually the line was carried north to the Angel in Islington, and more recently there has been completed a branch from the Angel to King's Cross, and another to Highbury is projected.

The length from Clapham Common to London Bridge is $4\frac{1}{4}$ miles; from London Bridge to the Angel, $1\frac{3}{4}$ miles; and from the Angel to King's Cross, $\frac{1}{2}$ mile; a total of $6\frac{1}{2}$ miles.

33. Nearly the whole of the Central London tunnels were excavated by hand labour, the cutting-edge of the shield doing no more than trimming the cutting to proper shape and size. But already, when the western half of this work was only partly completed, attempts were being made by the contractor, Mr. John Price, and his engineer, Mr. A. W. Manton, to use a boring-machine which would cut the whole section without any hand picking. The machine first used was mounted on a large driving shaft lying in the central axis of the tunnel, with a front bearing in the shield and a rear bearing upon a girder platform bolted to the rings of the completed part of the tunnel, which platform carried the driving engine operated by compressed air. The obstruction caused by this central shaft, engine, and gearing, and the difficulty arising in the adjustment of the bearings when the shield was rounding curves, caused trouble with this machine, although it did a great deal of useful work and demonstrated that the machine cutting-action was entirely satisfactory. In the tunnels now being excavated the bulk of the work has been done by an improved machine electrically driven.

In the Charing Cross–Hampstead railway the average weekly progress made with hand excavation was 50 feet, while the maximum was between 70 and 75 feet. Over 6 weeks in April and May, 1904, between Castle Road and Kentish Town on the Highbury line, the progress made with machine cutting was 78 rings of 20 inches length each, or 130 feet, per week of 128 hours, the work being carried on for 20 hours on each of 5 days, and 8 hours on Saturdays. The record progress in one week has been 85 rings, or 141½ feet.

On the Brompton–Piccadilly line the maximum progress made has been 78 rings per week. From February 6 to June 11, or in 18 weeks, 470 yards of tunnel were bored, giving an average of 26⅙ yards per week. Here 8 men were at the face with the machine, while 13 men were required without the machine.

Fig. 157 is a comparative diagram giving the weekly progress made by hand and by machine labour in the two tubes running side by side between Castle Road and Kentish Town. This record shows that the machine had the advantage of a straight run, while the hand-cut tunnel first dipped on a down-grade and then rose again. At the bottom of the dip one week was spent in advancing 4½ yards and changing direction; but this does not materially alter the average. The diagram gives 14 weeks of machine cutting and 19 weeks of hand cutting. The weekly averages are 32·9 yards by machine and 17·4 yards by hand labour. With machine excavation the weekly minimum and maximum were, setting aside the start when only 15 yards were cut, 19·6 and 46 yards. With hand cutting, putting aside the week spent in changing direction, the minimum and maximum were 12·9 and 23·6 yards.

For an 11 feet 8¼ inches tunnel, the actual cut taken per ring in the clay is 12 feet 8 inches by 20 inches. This means 7·77 cubic yards of excavation. The average amount of lime grouting used per ring is 6 cwt. The air-pressure required for grouting is 30 lbs. per square inch, although more is often used. The average time spent on one such cut is made up as follows:—

	Minutes.
Preparing for cutting, getting skips and conveyor up to face	12
Excavating	30
Preparing to build in lining, erecting stage for top rings and key	8
Erecting iron lining segments	18
Preparing for grouting, mixing lime, etc.	15
Grouting	28
Total minutes	111

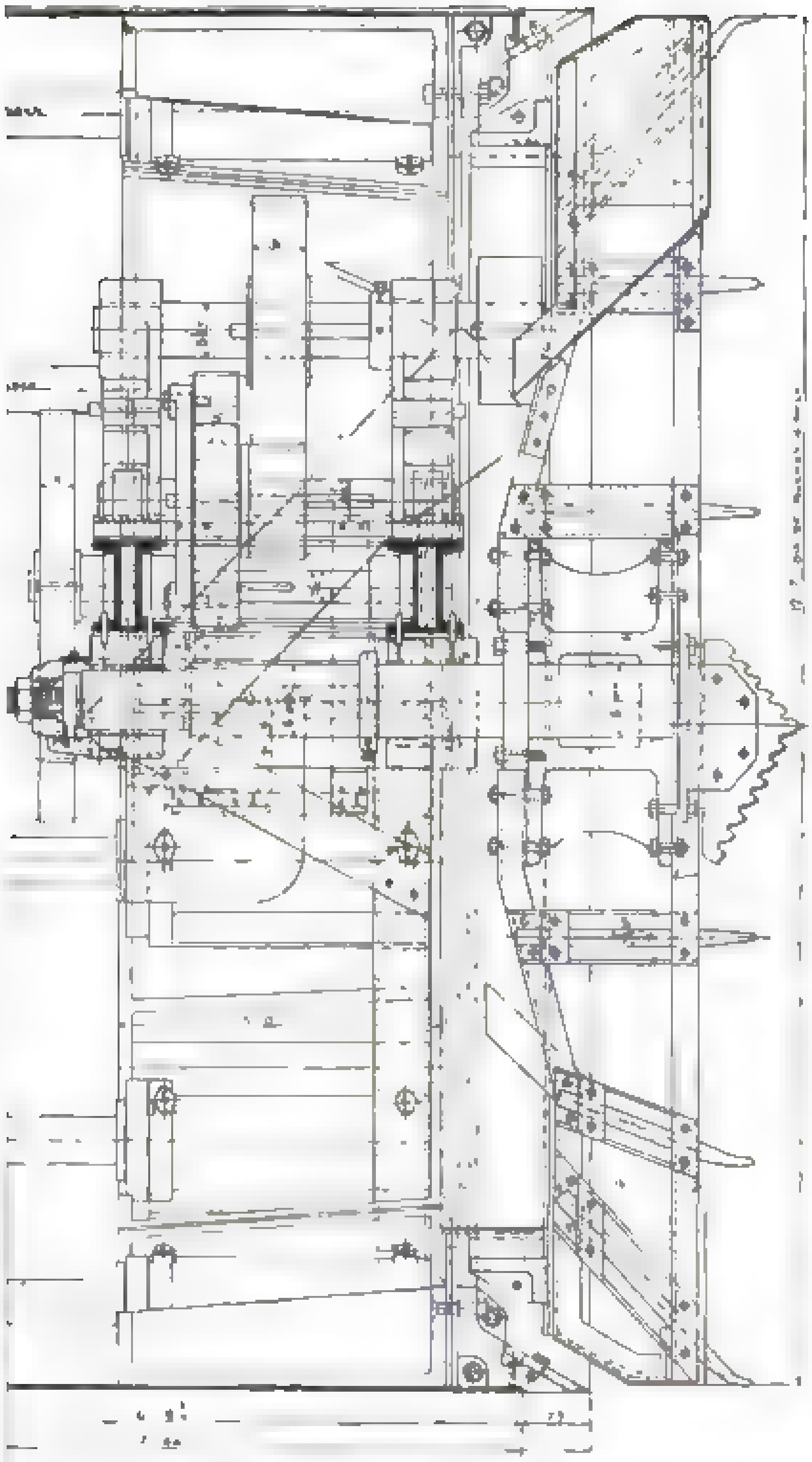


Fig. 159.—Section [To face p. 242
ter, with 10 rams.

Another estimate given to the writer was 75 minutes, but this was not so carefully made.

Each skip nominally carries away ¾ cubic yard of stuff. Actually it is found that in the main tunnels 30 skips, and in the large station tunnels 75 skips, are used per yard forward.

As an example of the progress made with the larger station tunnels, may be mentioned that at Charing Cross Road, 21 feet 2¼ inches inside, and 22 feet 6 inches outside diameter, where 223 rings, each 18 inches long, or 334½ feet, were completed between December 8, 1903, and April 28, 1904, inclusive of the time spent in setting up and again taking down the shield. The removal of the shield was commenced on March 17, so that the actual excavation and building of the lining occupied 3 months and 1 week.

The rate at which the sinking of the vertical shafts of 23 feet 11 inches outside and 23 feet inside diameter proceeds is about 1 ring of 4 feet depth per day of 24 hours.

34. Figs. 158, 159, 160, and 161 illustrate this boring-machine. The whole is commonly termed a "Digger Shield." The size illustrated is 12 feet 8 inches outside and 11 feet 8¼ inches inside shield diameter. It leaves ½ inch thickness outside the rings to be filled in with lime grouting. The rotary cutting-machine and the shield form one whole, the latter serving as frame and bedplate for the former. It is electric driven, the motor and gearing being mounted on the shield itself and the bearings being set on the cross-girder and vertical stanchions seen in Figs. 158 and 161. The tooling-drum is mounted on a short central shaft, in bearings 3 feet apart, centre to centre, as seen in Fig. 159, and of combined length 18 inches. The rear edge of this drum carries an internal toothed spur-wheel of 10-feet pitch diameter. The gearing between this and the motor is quadruple.

The motor runs normally at 610 revolutions per minute, and the working head at just over 1½ revolutions per minute, the gear ratio being 400 to 1. The head has six arms, on three of which three cutting-tools are fixed, while each of the other three carry two tools, or fifteen tools in all. These tools are 2-inch square bars of soft-tempered steel. These tools are best seen in Fig. 160. They need their cutting edges reset two or three times in a week on a stony working face, but only about once a month in cutting pure clay. A large central drill-bit is also carried by the rotating shaft. The motor is series wound, and varies its speed with the hardness or softness of the ground to be cut. According to the electric supply available in the various London districts, 200-volt and 400-volt motors are used. Running light 6·6 kilowatt are absorbed, and with average cutting load 17·6 kilowatt.

The rotating drum carries six buckets, which catch the clay

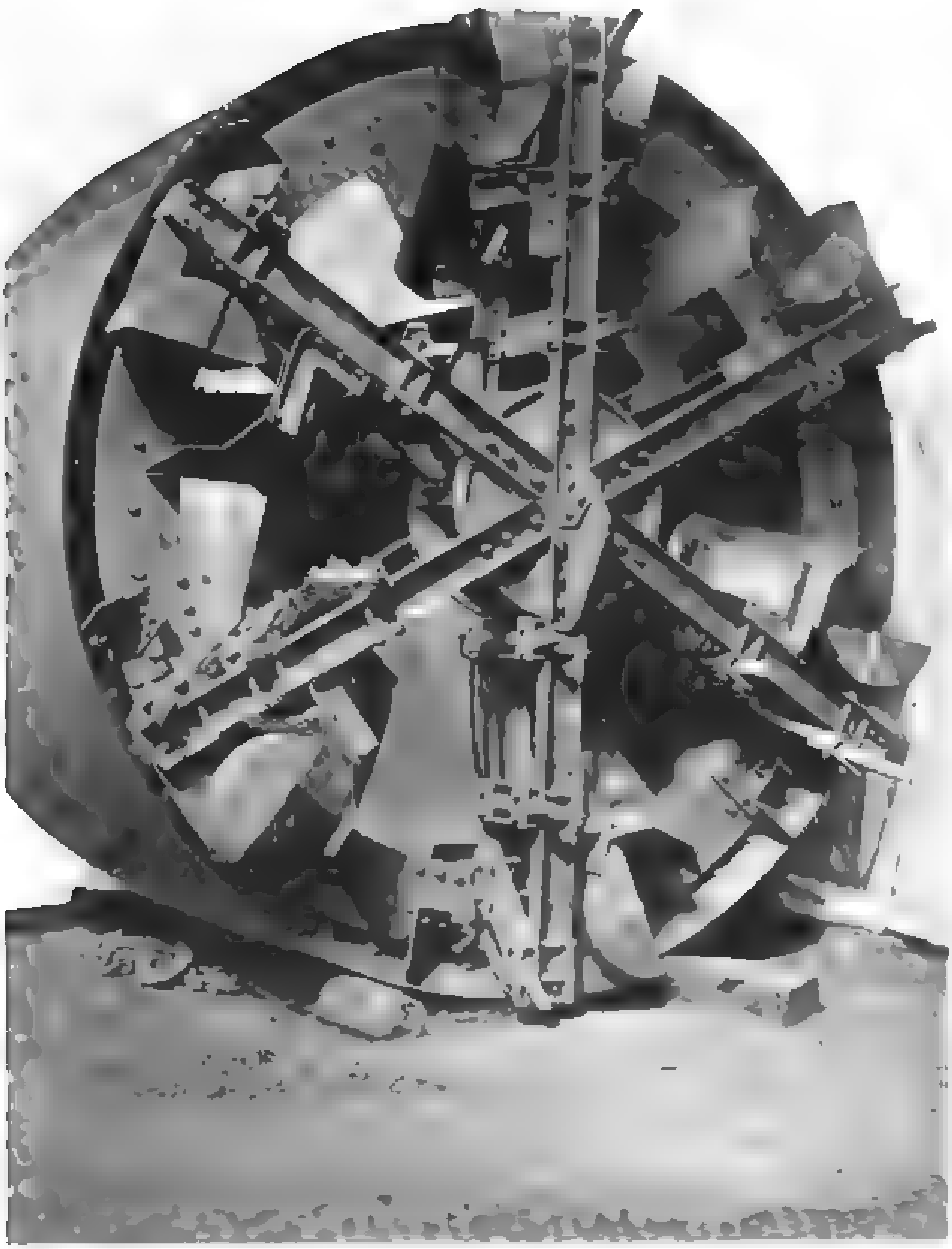


Fig. 160.—Price's Tunnel Excavator—Working Front.

pared off by the tools. Along with each bucket is fixed a short shoot rotating with the drum. As each bucket comes to the top of the circle it empties itself into its own shoot, whence the clay at once falls on to a belt-conveyor. This conveyor carries it some distance back from the working face to the tram-road laid along the completed portion of the tunnel, and here tips it into waggons brought up on these ways. The empty waggons, or tubs, are pushed up by hand, and when loaded are mostly drawn away by ponies. The conveyor fills these through a hopper, which has three discharge doors, one at its rear end and two at its side; so that by suitably marshalling the tubs the process of loading and carrying away is quite continuous and no accumulation of stuff occurs. The conveyor is motor driven. It absorbs 1·76 kilowatt running light, and about 3·5 kilowatt when at full work. This boring-machine costs about £1500.

On the Charing Cross–Hampstead line six diggers are in use. Four of these are always working, while two others are being dismounted after boring a section or being re-erected in a new section.

At the Earl's Court Station excavation the stuff for 1600 rings has to be taken away, and this is being done by a conveyor driven by a 10 horse-power shunt-wound motor actually working at about 5 horse-power. All the work in the Earl's Court district is done by electrical energy supplied from West Kensington generating station by a 200-volt direct current dynamo of 37½ normal kilowatt power.

According to local facilities for obtaining electric energy, the methods adopted are very various. For instance, at Belsize Park energy is drawn from 2000-volt single-phase mains at 90 periods per second. A static transformer transforms this to 205 volts, and this secondary current drives a 100-horse-power single-phase synchronous Heyland motor, started by a small single-phase induction motor. This motor drives a "Manchester" direct-current dynamo, whose normal output is 170 ampères at 440 volts.

At Golder's Green, 2000-volt 90-frequency single-phase current is static transformed to 210 volts, and the secondary current drives a Wengstrom induction motor direct-coupled to a direct-current dynamo giving 120 ampères at 440 volts. This induction motor has a plain water-resistance rheostat in the circuit of its rotor.

At the Hippodrome working-station one finds a 50 horse-power 6-pole direct-current 200-volt motor driving two four-cylinder air-compressors of Messrs. Reavell's manufacture. These compressors have four pairs of cylinders spaced at right angles round the driving-shaft. Each tandem pair of cylinders is a two-stage compressor, all single-acting and all driven from one crank-pin. It compresses

FIG. 161.—Price's Tunnel Excavator—Rear Face.

350 cubic feet of atmospheric air per minute to 80 lbs. per square inch pressure.

35. The three railways which pass under the Thames have had, in doing so, to encounter special difficulties from water. The Baker Street and Waterloo railway was delayed by trouble from an unexpected dip in the upper surface of the clay, so that the two tunnels had to be driven through clean gravel and sand forming the bed of the river. The surmounting of these difficulties, however, belongs to civil and not to electric engineering, and cannot be described in this book. The reader can only be referred to papers in which the authors deal very fully with these subjects. The Baker Street–Waterloo under-river tunnelling was described by Mr. A. H. Haigh in vol. 150 of the "Proc. Inst. C.E." Mr. J. H. Greathead dealt with the "City and South London" tunnel in vol. 123. "Proc. Inst. C.E."; and Mr. H. H. Dalrymple-Hay had a paper on the "Waterloo and City" tunnel in vol. 139 of "Proc. Inst. C.E."

The electrical equipment of the City and South London line and its working results are of great interest, partly because of its being the first of these deep-level lines, and partly because it is the only important example of the use of three-wire direct-current long-distance transmission for heavy railway traffic. It is, however, the less necessary to describe it here because it has been very ably dealt with in two lengthy and detailed papers by Mr. P. Valentine McMahon, the chief engineer of the line, which the reader will find in vol. 28 (1899) and vol. 33 (1904) of the "Journal Inst. Electrical Engineers."

CHAPTER VIII

LONDON SURFACE AND SHALLOW ELECTRIC RAILWAYS

1. Old-fashioned London—**2.** Low *versus* High Tension—**3.** Metropolitan and District Railways—**4.** System of Third and Fourth Rails adopted—**5.** Rail bonding—**6.** Collecting Shoes—**7.** Bogie Trucks—**8.** Motor-cars—**9.** Control Driving—**10.** Master-Controller in Driver's Cab—**11.** Main Turret Controller—**12.** Safety Appliances and Series-parallel Control—**13.** Power required and Running Cost—**14.** Distributing Feeders and Sub-stations—**15.** Transformers and Converters—**16.** Feeder Cables—**17.** Neasden Central Power Station—**18.** Barometric Condensers—**19.** Cooling Towers—**20.** Generators—**21.** Exciters—**22.** Steam Turbines—**23.** Switchboard Galleries—**24.** Master Control Desk—**25.** Synchronizer—**26.** Time-limit Relay—**27.** Bus-bars and Main Oil-switches—**28.** Control Operating System—**29.** Overload Relay Switch—**30.** Chelsea Generating Station—**31.** Boilers and Stokers—**32.** Steam Turbines and Generators—**33.** Switch Galleries—**34.** Control and Distribution—**35.** Newcastle-Tyneside Electric Railways—**36.** Liverpool-Southport Electric Railway—**37.** British Manufacturers.

1. London is a big unwieldy problem, and has therefore lagged long behind the rest of the world in providing herself with most kinds of modern conveniences. But the result of these delays is that whatever is done in London is done by the light of a vast amount of experience gained in other parts of the world. Electric traction, already long in use in almost every other part of the world, is now being introduced in London; and, as these London installations are the latest and most modern each in its own kind, they will serve here as the best illustrations of the present development of this department of engineering science. They are also of very special interest because of the uniquely heavy duty they are called upon to perform.

2. In one sense they are not of the most modern kind. In other places engineers are allowed to be more daring in adopting methods that have not undergone the test of year-long trial. A stiff fight for the use of high-tension electricity in the electrification of the Metropolitan and District Railways was fought in the Court of Arbitration held in the autumn of 1901. Low-tension carried the

day because low-tension systems had been well tried for many years in America, whereas high-tension, although successfully carried out on a small scale in several places, was considered to be still in the experimental stage. Considered from the non-technical and non-expert points of view, the decision was no doubt well justified, because of the very large financial and public interests at stake, which it would have been wrong to expose to any risk of failure. Nevertheless, well-informed and experienced electrical engineers regretted the decision, and there is little doubt that ten or twelve years hence, when the present continual extension of high-tension systems have familiarized the English public with their economic merits and their comparative safety, the London surface and shallow railways now near completion will be thought as old-fashioned as their filthy smoke-and-sulphur-choked Underground has been regarded for fifteen years past. Thus does London insist on marching always in the rear rank and living on the standard of comfort appropriate to a past generation.

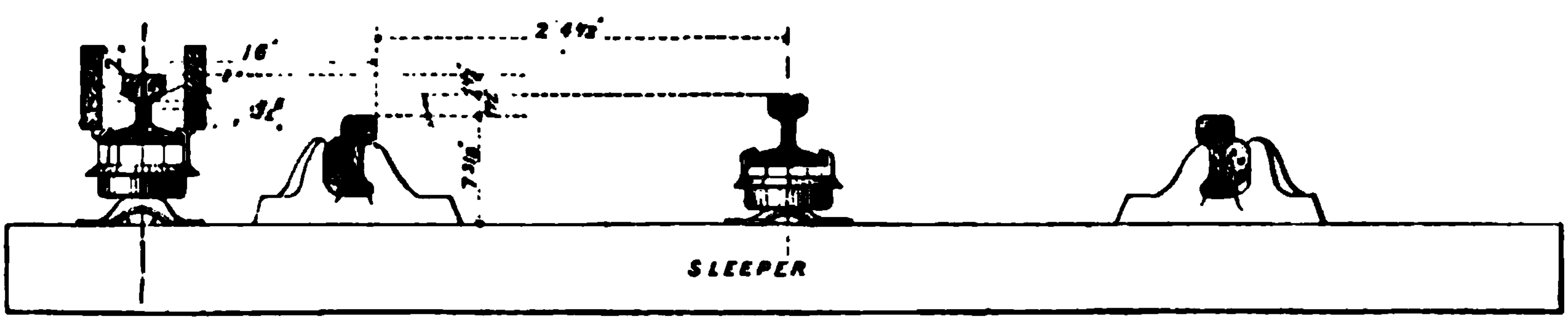


FIG. 162.—Section of Track, Metropolitan Railway.

3. The Metropolitan and the Metropolitan District, two financially distinct companies, run so many trains over each other's lines, and each has to run on its lines trains coming into London from so many outside companies, that it was a necessity that in their electrification they should adopt systems with the same basis. They have to work conjointly the new extension from the City to Whitechapel and Bow. A short length of the Circle is owned by them conjointly; and the Metropolitan Inner Circle trains all run on the District lines. The Great Western, the London and North Western, the Great Central, and the South Eastern Railways all have running powers over the rails of one or both of the two companies.

The map (Fig. 156) in Chapter VII. shows the major part of the joint system.

The Metropolitan Central Power Station is at Neasden, outside the extreme north-east of London, beyond Willesden Green. From here their line extends westwards through Harrow to Aylesbury, with a branch 7 miles long from Harrow to Uxbridge. In the other

direction it passes through Swiss Cottage to Baker Street, to join there the Inner Circle. From Aylesbury to Baker Street is about 10 miles. From Aldgate at the east end to South Kensington in the west, the northern part of this Inner Circle is owned by this company, a length somewhat under 8 miles. Branching from this circle, the Great Western line from Edgware Road to Hammersmith is to be electrified as part of the present undertaking.

The Metropolitan District Central Power Station is placed at the west end of Chelsea, on the north bank of the Thames. This company owns the southern stretch of the Inner Circle; a branch from Whitechapel across the Thames to New Cross; and the lines from South Kensington to Wimbledon and to Chiswick, whence radiate branch lines to Richmond, Hounslow, and South Harrow. At the east end of the Inner Circle a length of 1 mile 9 chains is owned jointly by the two companies.

The Metropolitan extends far north of the limits mentioned above, which are those to which electrification has now been extended. Their total length is 67 route miles, of which 26 have been electrified. To this is to be added nearly 4 miles from Edgware Road to Hammersmith on the Great Western. The rest will, no doubt, follow within a very few years. The Metropolitan District route length is about 33 miles.

4. Fig. 162 shows the track system adopted. The line current is supplied to the cars at between 500 and 600 volts from an insulated surface rail lying 16 inches outside and to the left of the two running rails. The return is by a fourth rail also insulated and laid along the centre line of the track. The track rails are not used electrically. Thus no disputes regarding vagabond earth-currents and electrolytic corrosion of pipes or electro-magnetic disturbance of instruments can arise, and at the same time the engineers have not to contend with the Board of Trade 7-volt and other restrictions.

In passing, it may be noted how all large modern traction installations are steadily gravitating towards insulated returns. For fifteen years the present writer has advocated this policy, and has pointed out that it will gradually become a practical necessity as the amount of electrical power transmitted per acre of land surface becomes very large.

The positive-rail is placed at 3 inches higher level, and the return-rail at 1½ inch higher level, than the two running-rails. At stations, sidings, and everywhere where workmen of any kind have to pass frequently, the outer positive-rail is guarded by two wood-plank guards, as shown in Fig. 162.

The third and fourth rails have equal sections, 10 inches square and 100 lbs. per yard length. They are of a 0·05 per cent. carbon

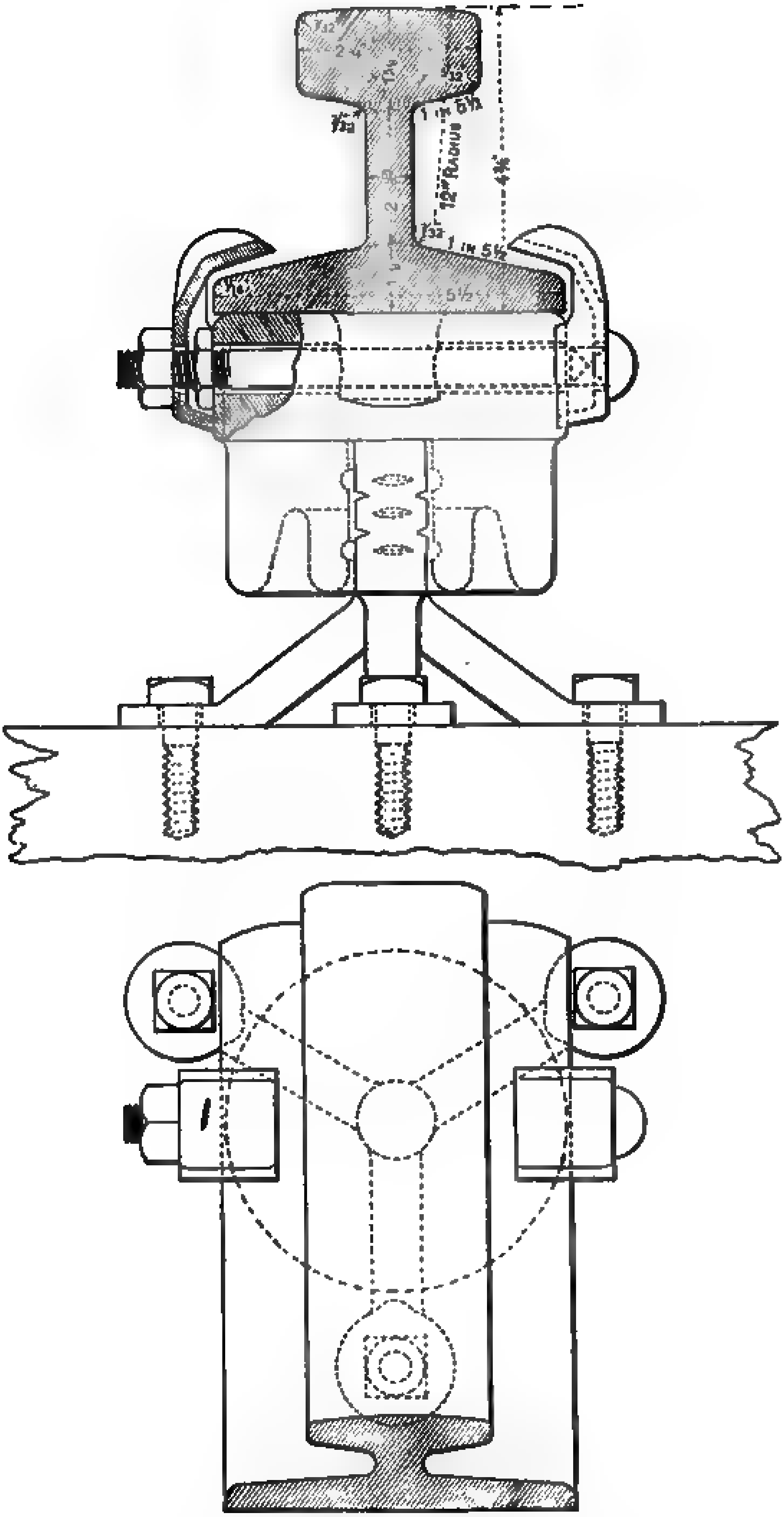


Fig. 163.—Conductor Rail, Metropolitan Railway.

basic steel with electrical conductivity equal to that of copper divided by 6½. This rail-section and the insulator for the third rail is shown in Fig. 163. The insulator for the fourth rail is of the same pattern, except that its three metal legs are 1½ inch shorter in vertical height. It has a plain cylindrical body of 5½ inches diameter by 4½ inches deep of highly vitrified white porcelain. This is traversed by a horizontal hole, through which passes a ½-inch bolt with a solid rivet-head on one end and two nuts on its other end. This fixes to the porcelain body two claw-clamps, which secure the rail lying on the flat top of the porcelain. The object of the second

FIG. 164.—Conductor-rail Bonds, Metropolitan Railway.

inner nut is to fix the inside clamp independently of the outside clamp.

The porcelain body is hollow underneath, giving, with its porcelain boss, two drip-edges. Its recessed boss is cemented on the upper stem of a three-legged iron support, the feet of the three legs being fixed by coach-screws to a transverse wooden sleeper. A rail can be removed without disturbing the insulator, and any insulator can be removed, and a new one inserted without moving the rail. These insulator supports are spaced about 8 feet apart. The test insulation for each insulator tested separately under water was 300,000 megohms.

The running-rails are bell-headed, of 86 lbs. per yard weight.

5. The bonding of these 42-feet rails is particularly substantial. Figs. 164 and 165 show the bonds. There are two short side bonds and one long central bond, each a lamination of copper strip with solid copper ends cast on. These are riveted by a hand-pump hydraulic riveter to the bottom flanges of the rails—the short bonds by one rivet and the long bond by two rivets in each rail. The copper section of the three bonds is 1½ square inch.

6. The current is collected from, and returned to, these rails by cast-iron sliding shoes pressed down on the rail, each by one spiral spring, and dragged in either direction by one of two oblique links,

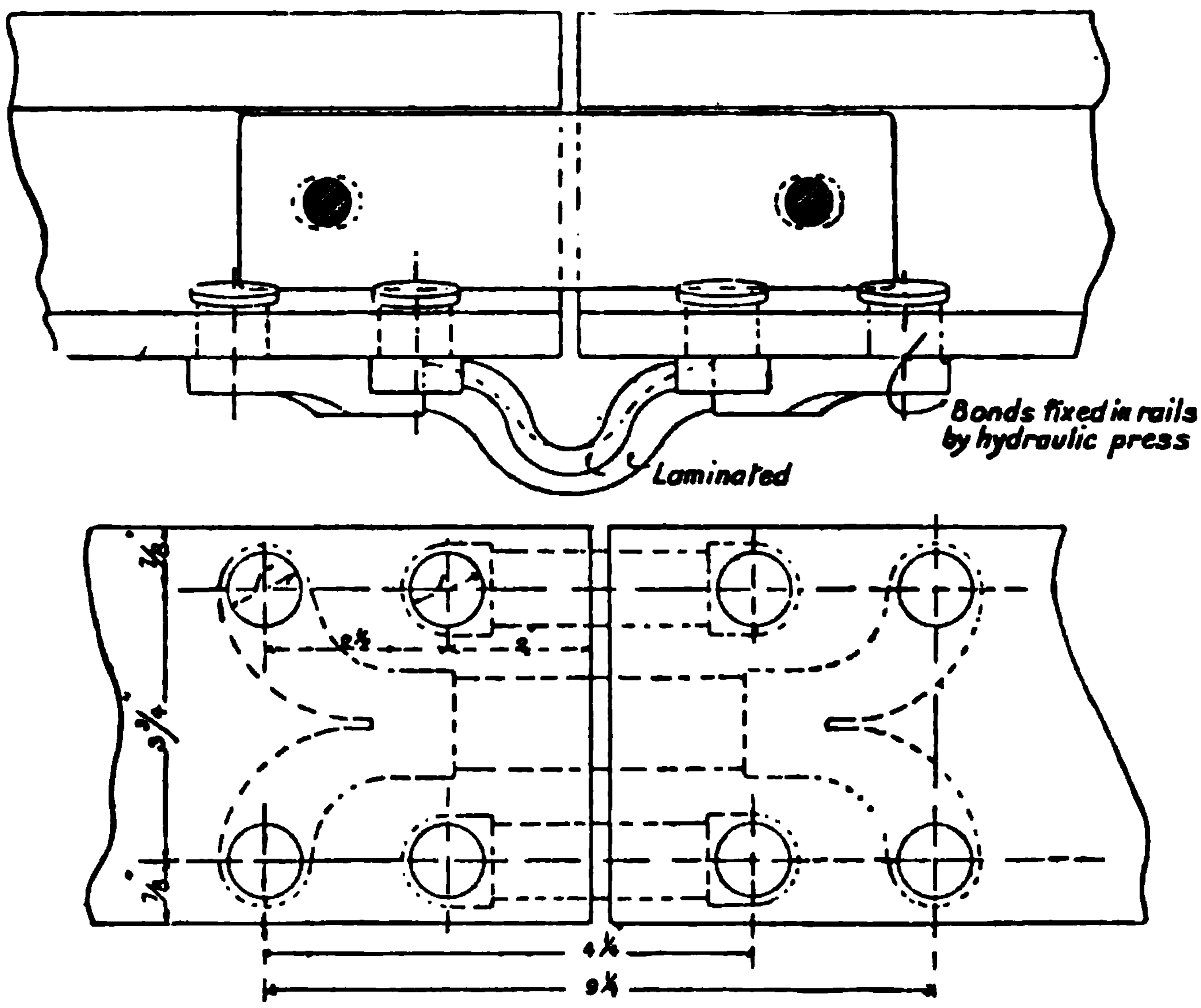


Fig. 165.—Elevation and Plan of Bonds of Conductor Rails.

by which it is hung to a timber cross-beam on the car-truck. The shape of these shoes is sufficiently well seen in Fig. 166. A pair of shoes is placed tandem on the same rail, and there are three pairs of them. The central pair slides on the return fourth rail. The left-hand outside pair normally picks up the current from the third rail, while the right-hand outside pair is normally hanging idle. But as the cars are built to run either end foremost, either outside pair may become the left-hand working collectors. Also at crossings and points there are breaks in the third rail, as its 3-inch superior level does not enable it to pass over the running rails, while it is still less able to pass over the fourth rail which is only 1½ inch lower. These

FIG. 166.—Current Collecting Shoes for Third and Fourth Rails, Metropolitan Railway.

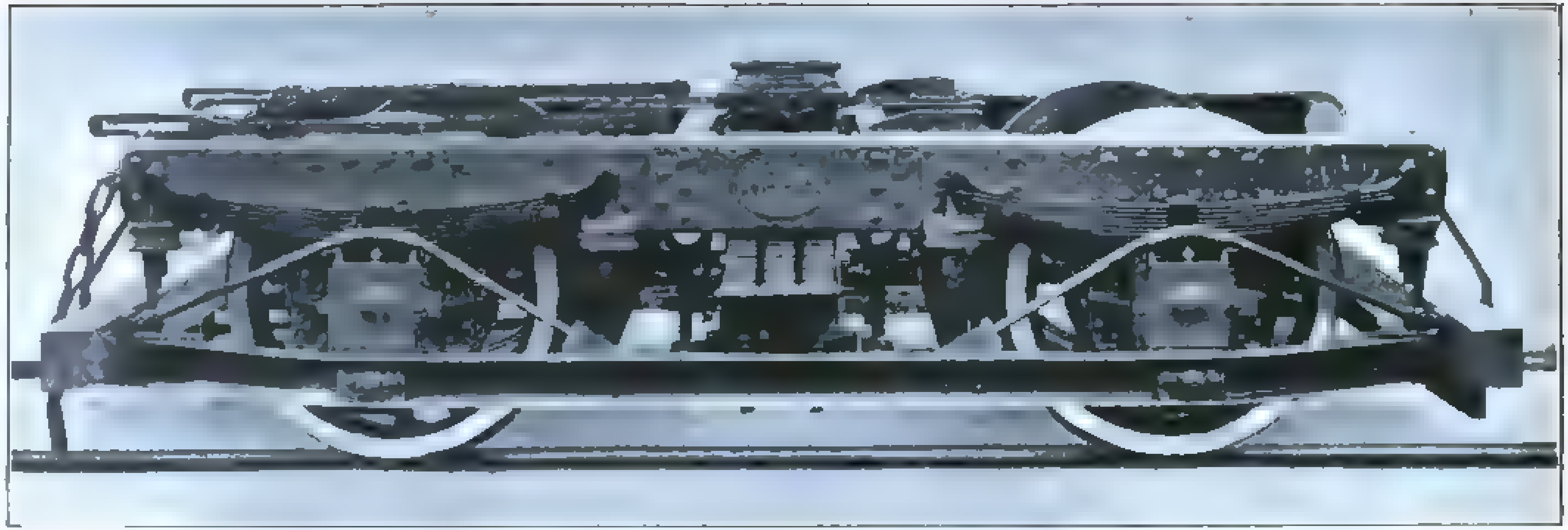


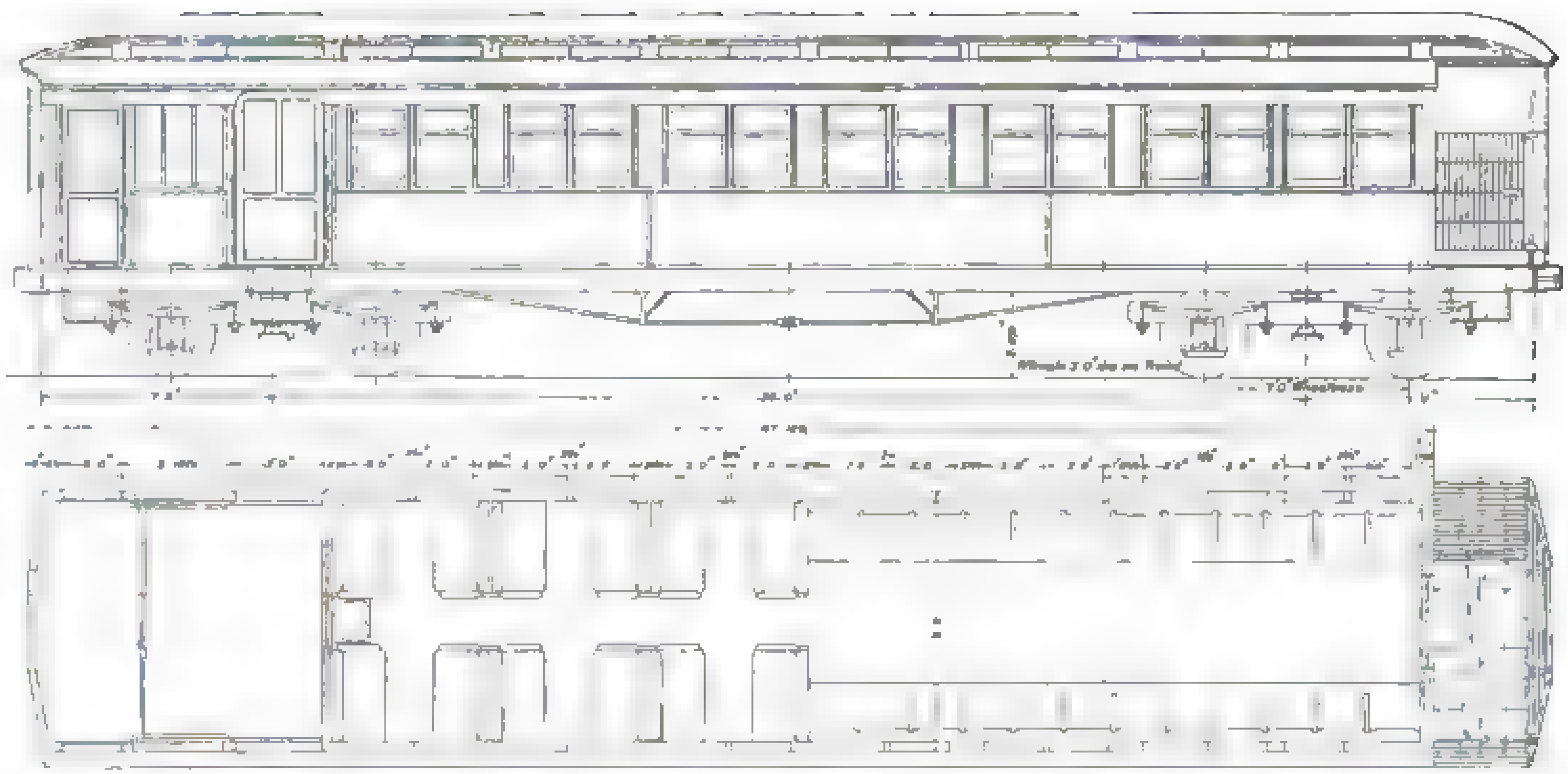
Fig. 167.—Motor-truck, Metropolitan Railway

breaks are, of course, bridged underneath by copper bonds covered with insulating material. Throughout the lengths of these breaks short lengths of positive conducting rail are laid at the right-hand of the track, and are bonded to the main positive rail. In passing the crossings the right-hand pair of collecting shoes slides upon these extra short lengths, so that there is no interruption in the supply of the current.

7. Fig. 167 is a side view of one of the motor-car bogie trucks of the Metropolitan rolling-stock. Its wheel base is 7 feet and wheel diameter 3 feet. The top side-bar of the frame is carried by long-span plate-springs centred on the axle-boxes, and the bolster by two transverse triplex double-bow plate-springs. The frame-bars are pressed steel forgings, and the horn-plates and axle-boxes are steel castings. The axle-journals are 4 inches diameter by 8 inches long. The bottom bars of channel iron tie the axle-boxes together, and are braced to the tops of the axle-boxes by oblique rods of round section. These trucks weigh, exclusive of motors, 5½ tons each. Each carries two 150-horse-power motors, so that a motor-car carries four, or 600 nominal horse-power. Each train has two motor-cars, one in front and one in the rear, with four coaches between them. Thus each train is furnished with 1200 driving horse-power. The motors have the usual spring nose-suspension, and are geared in the ratio 17 to 54. Westinghouse air-brakes are used, with one block to each wheel hung on the inside. This power is calculated to be sufficient for a speed of 40 miles per hour on the level with a train of 150 tons weight.

8. Figs. 168, 169, and 170 give the elevation, plan, and end view of a motor-car. Its extreme height above rails is 12 feet 2½ inches, and extreme width 8 feet 9 inches. The distance between the two bogie-trucks is 35 feet between centres, and the carriage is 52½ feet long over buffer-beams. It is seated for 49 passengers. The trailer-cars are very similar in body construction, but afford space for 56 seats. Fig. 171 gives an outside perspective view of one of the motor-cars.

The cars are entered by sliding doors at the ends only from end platforms. These platforms are shut and opened by swing gates controlled by the conductor. The maximum size of train is made up of four second-class and two first-class carriages, the latter being placed in the centre. They are lighted and heated electrically, there being thirty 32-candle-power lamps to each car. They are built to a large extent of fireproof material. In each motor-car a luggage compartment intervenes between the passenger saloon and the driver's box. The main members of the under-frame are 9 inches by 3 inches by $\frac{7}{16}$ inch channels of Siemens-Martin steel. The flooring is of sheet steel, as are also the lower panels and the inside lining. Teak and oak are used for the window-frames and the interior furniture,



FIGS. 168, 169.—Elevation and Plan of Motor-car of Metropolitan Railway.

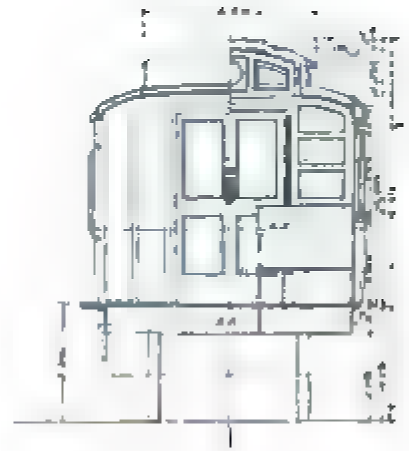


FIG. 170.—Cross Section, Motor-car.

S

FIG. 171.—Motor-car, Metropolitan Railway.

and the roof is lined with asbestos millboard. The unloaded weight of a motor-coach fully equipped is 39 tons, and, as all the four axles are driving-axles, the whole of this weight is available for rail adhesion.

The 500-volt cables leading to and from the controllers and between the controllers and the motors are covered (1) with vulcanized rubber, (2) with double thickness of fireproofed asbestos braid, (3) with fireproofed jute braid, and are (4) encased in grooved asbestos slate. None of these cables come above the sheet-steel floors of the cars.

9. In Fig. 169 it will be observed that the driver's cab is quite small. None of the main switching or other controlling apparatus is in this compartment, and no high-tension (500-volt) currents come into it. The apparatus within reach of, and to be handled by, the driver consists of a switch-board regulating (1) the car-lighting, (2) the air-compressor, and (3) a small 7-cell secondary battery, and of

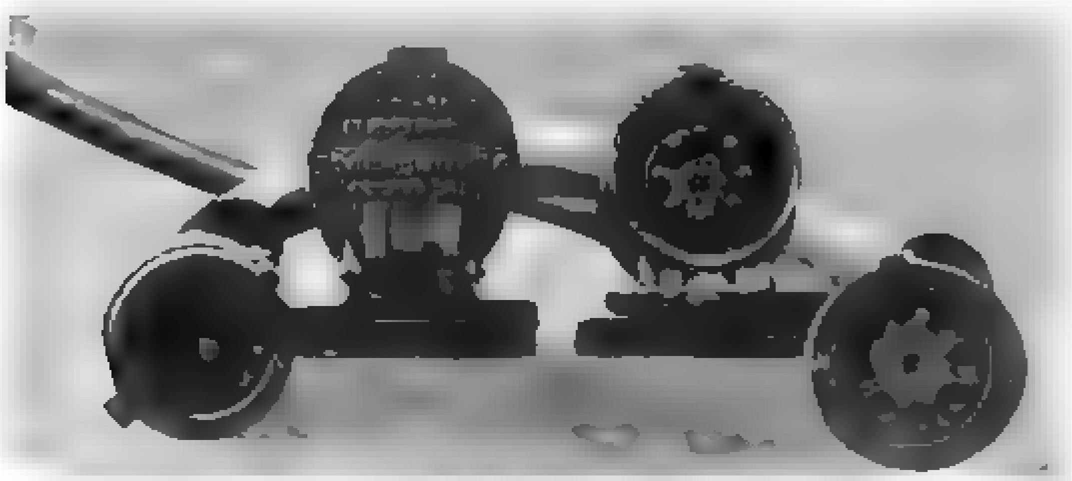


FIG. 172.—Nine-way Control Cable.

(4) a "master-controller." None but small weak-tension currents come into the operation of these apparatus; the making and breaking of these small currents are attended by no risks or difficulties of any kind, and no magnetic blow-outs or other bulky and complex arrangements are needed to prevent sparking, flashing, or burning of the contacts.

All the electrical equipment is the work of the British Westinghouse Co., to whose engineers, and to Mr. Thomas Parker, the chief consulting electrical engineer of the Metropolitan Railway Co., the author is obliged for much information and for many illustrations, some of the latter being reproduced from the *Tramway and Railway World*, with the permission of its publisher.

Along the length of the train run two operative connections, (1) a "nine-way" control cable for small weak-tension currents, and (2) a compressed-air pipe. These are connected from coach to coach

by easily connected or disconnected joints. Fig. 172 shows two male and two female joint ends of the nine-way cable.

The two trucks at the two ends of one motor-coach are entirely independent electrically so far as main current supply and main control switches are concerned. But the four motor-trucks in a complete train always act in identical manners in respect of driving

FIG. 173.—Master-controller on Car.

and braking, and these actions are all simultaneously and definitely prescribed by the operation of the master-controller and switch-board in the driver's box on one (the leading) motor-coach. The prescribed action is dictated and transmitted throughout the length of the train through the control-cable and the compressed-air pipe.

10. Fig. 173 gives a view of the master-controller in the driver's

cab, and Fig. 174 is a plan of the top of its case, showing plainly the handle moved by the driver. Fig. 175 is an inside view, with the doors thrown open, of the two upper and lower parts of this controller. Compressed air is used not only for braking, but also for moving all the main switch apparatus. In Fig. 173 are seen the handles whereby the supply of compressed air is directed. The whole of this apparatus is quite small, and occupies only a few cubic feet of space. Compared to the main switches and other apparatus it controls, it is properly described as a toy mechanism.

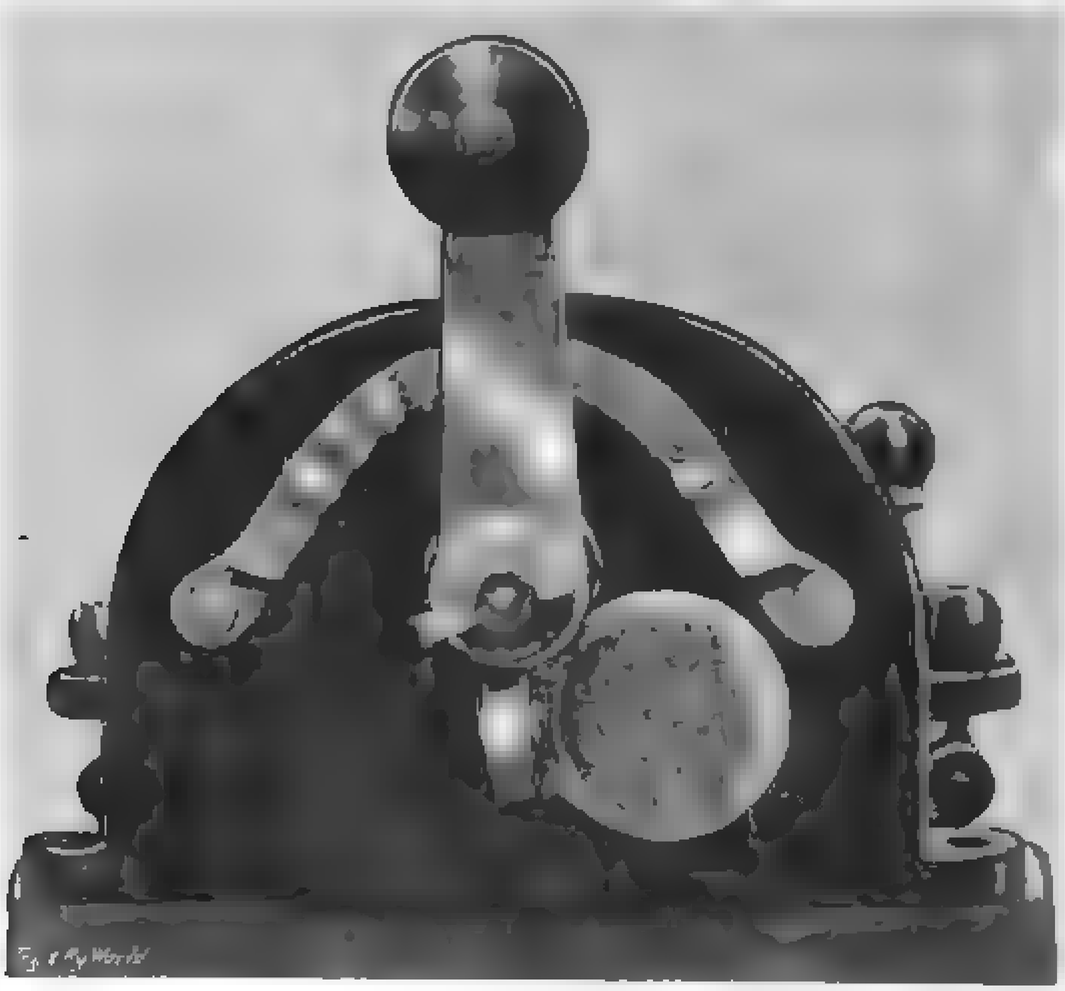


FIG. 174.—Top View of Master-controller.

11. The small currents from this controller excite fifteen electro-magnets placed in the boxes V of the "turret-controller" seen in section in Fig. 176, and in outside view in Fig. 177. This is the controller switching the main working current. There is one such controller for each motor-truck, hung below the floor of the coach. Hung beside it in two tiers, and also below the floor, and exposed to the cooling action of the air-draught under the coach, is a row of resistance boxes, the whole group of which form the rheostat for the series-parallel working of the motors.

The electro-magnets in the boxes V open small steel needle-point

valves, which admit air-pressure to the cylinders A through the ports P from the air-box C, which is supplied through the pipe R from the main air-reservoir of the air-compressing pump. This pump is driven by an electro-motor, the current to which is cut off automatically when the air-pressure reaches 90 lbs. per square inch, contact being made again when the pressure has fallen to about 80 lbs.

In the cylinders A are pistons pressed upwards by spiral springs when there is no air-pressure above them. The piston-rods are linked

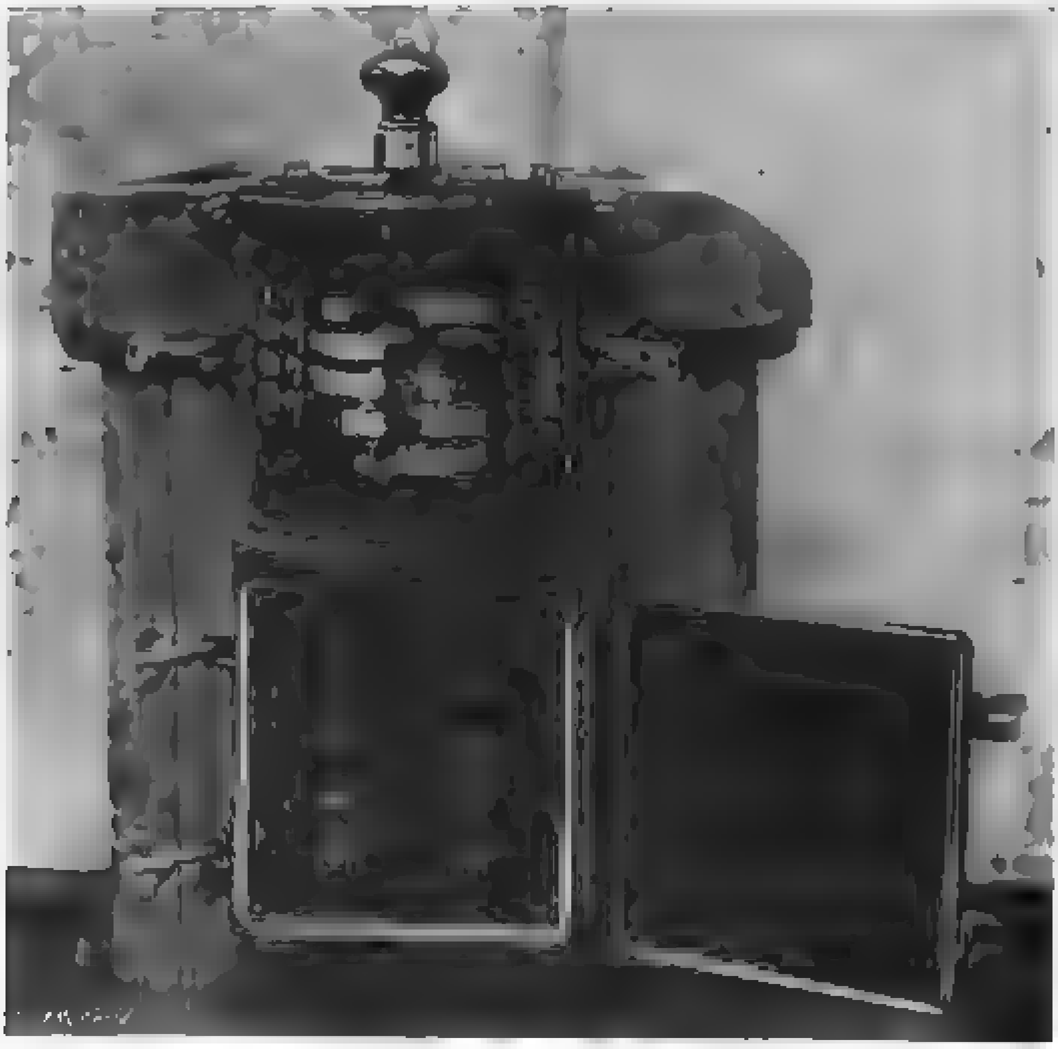


FIG. 175.—Interior of Master-controller on Car.

to the switch-levers S. When the pistons are up the switches are open. Contact is made at any one point when compressed air is admitted to the cylinder and the piston pushed down.

The contact faces are flat metal plates. A special spring attachment to the lever causes a slight rolling and rubbing motion at each contact made, and this keeps the surfaces clean, bright, and even. Each such switch closes and opens inside a rectangular box, well seen in Fig 177, made of a good insulating material called "vulcabeston." The fifteen switch-boxes are arranged in a circle under

the circular base-plate of the controller. This arrangement gives its name of "turret" to this form of "multiple-unit" controller.

Between each two neighbouring switch-boxes is interposed a magnet-pole of $\sqcup$ section. These poles are placed alternately thus $\sqcup$ and thus $\sqcap$, and they are alternately north and south poles. The magnetic flux comes from a solenoid winding on the drum B standing vertically in the centre of the controller. The magnetic circuit is completed between the north and south poles by magnetic flux running horizontally through the switch-boxes, that is, at right angles to the current direction between the two contact-plates of each

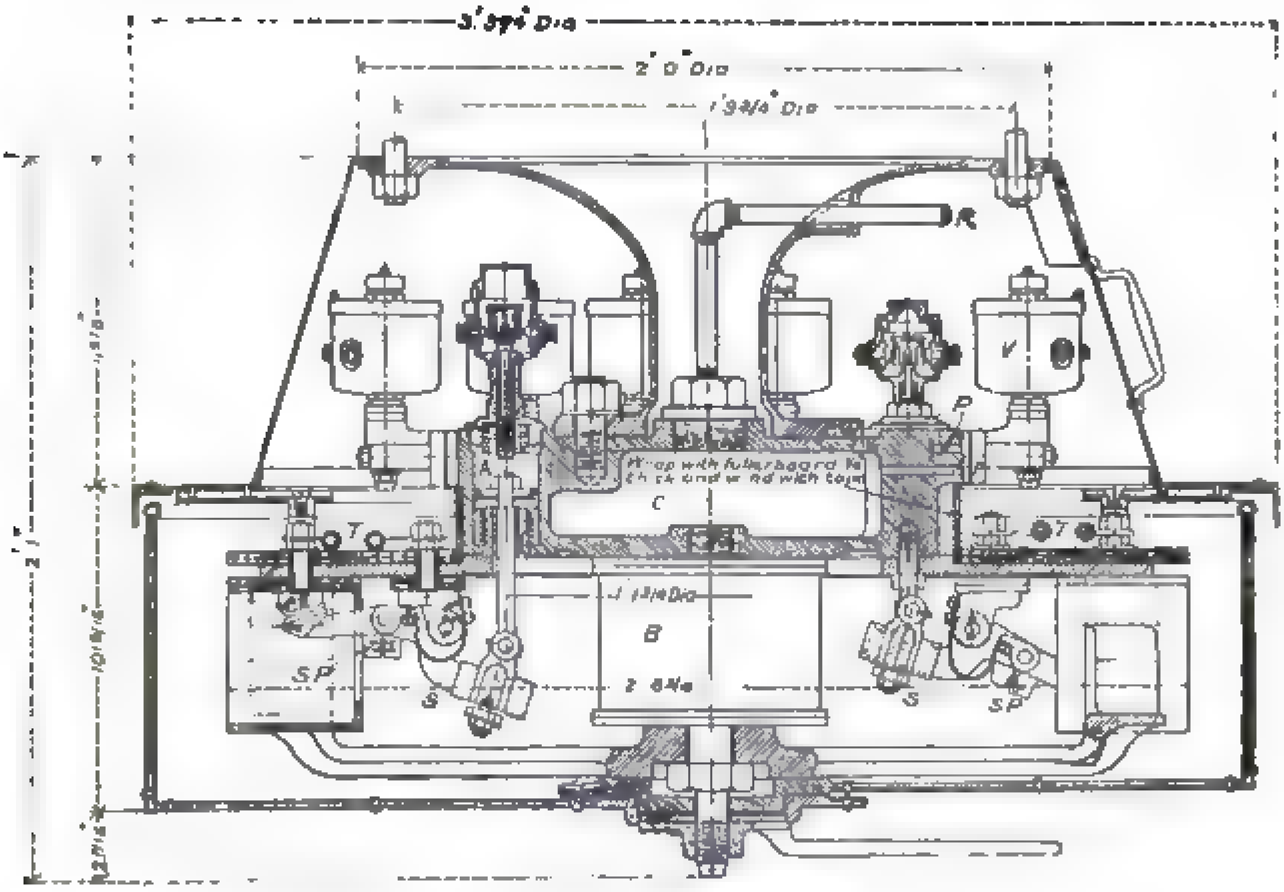


FIG. 176.—Section of Turret-controller.

switch. This single solenoid, B, therefore, acts as a magnetic blow-out for all the fifteen switches.

12. One of the contacts in the turret controller is the main switch, making or breaking the connection to the collecting shoes. This switch is opened automatically by exhausting the air from its cylinder, A, whenever the current-load rises to the limit considered safe for the insulation of the motors. It is opened automatically also when the line voltage disappears or fails to transmit to the collecting shoes, from whatever cause such failure arises. When this "no-voltage" safety cut-out operates, the controller throws a high resistance into the path of the re-starting current, and thus provides automatically against the risk of sudden new rush of excess current

through the motors when the cause of the stoppage of the voltage is removed.

As the handle of the master-controller is moved round from the "neutral point" between the "forward" and "backward" segments, it passes through five "notches." It first sets the emergency brake valve ready to act in case of need, so that, independently of the driver, no driving is possible without this brake being prepared to operate. The next step closes the main switch above referred to. At the next step the two motors are put in circuit in series, with all the rheostat resistance in. Further motion of the handle starts automatic cutting-out of these resistances. These are cut out at a prescribed time-rate, regulated by an electrically driven governor, which the driver has no power to overrun by moving his handle further round too quickly. However fast he may throw it over to the next stop, the switches in the turret-controller will throw over, one after the other, at the prescribed time-intervals; and his placing the handle at the full forward notch has no effect until the process of throwing over all the switch-levers and cutting out all the resistances has been accomplished at this definite time-rate.

After all these resistances have been cut out, if the driver have already brought the handle to this next notch, or as soon as he does so, the controller switches the motors in parallel, at the same time inserting again the full resistance, and the automatic cutting out of these resistances at the prescribed time-rate recommences.

The driver moves the handle of the master-controller against the resistance of a coiled spring, and if, from sudden illness or carelessness or other cause of incapacity, he loses his hold of the handle, it immediately flies back to the neutral position in which the motors are deprived of all driving current.

The motors are reversed by carrying the handle through the neutral position towards the backward segment. The driver is, however, given no power to effect the reversal with dangerous suddenness. As soon as the handle has left the neutral position, its motion starts into action a small air-engine, the air to drive this engine being admitted to its ports by a needle-valve, which is moved by an electromagnet excited from the master-controller. Only through the action of this air-engine are the necessary contacts made to effect the reversal of the motor drive.

13. In the provision of power the rail conductors are estimated to cause a maximum potential drop of 8 per cent. At certain places where the demand for power is not large the peak load will give 10 to 15 per cent. potential drop. There are no copper feeders used on the low-tension system, the sub-stations all being situated on the line, and the low-tension copper cables to the rails being therefore only a few yards in length. The negative terminals in the

sub-stations may be earthed or insulated at will; they will probably be earthed in ordinary working.

The normal train-weight is 150 tons. Some trains are 200 tons, while others are 75 tons, the latter being run with a single motor-coach. The power at present being provided is for 38 full-sized trains running simultaneously on the whole Metropolitan system. A hundred watt-hours per train ton-mile at average speed 15 miles per hour, inclusive of stoppages, are allowed, and the present power-supply is equal to satisfying a demand for 120,000 train ton-miles per hour. This multiplied by 100 watt-hours means 12,000 kilo-

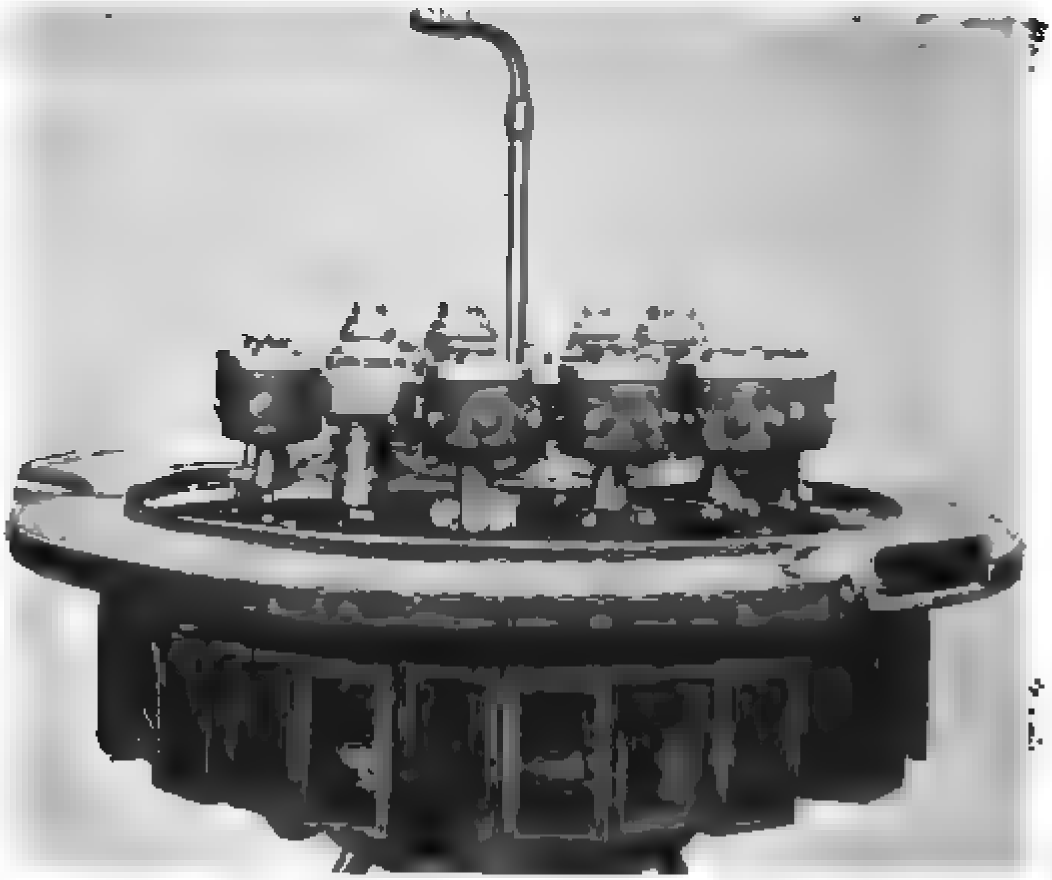


FIG. 177.—Turret-controller on Car (uncovered).

watt supplied to the coaches. Four units, each rated at 3500 kilowatt, have been put down in the Neasden power station, giving a normal full output capacity of 14,000 kilowatt without overloading. Each of these units has a steady overload capacity of 25 per cent., so that three units can supply 13,000 kilowatts.

The power here stated is estimated to cover train acceleration at $1\frac{1}{2}$ feet per second per second, which is sufficient to send the trains round the complete Inner Circle in 50 minutes, inclusive of stops.

The engineers' rough estimate of the total running expenditure is £20 per train ton-year.

The rolling-stock of 38 full trains will cost about £346,000, and

the power station about £174,000. The complete electrification of the line, including central and sub-stations, feeders, rails, and rolling-stock, will cost, on the basis of the present traffic, over 1¼ million pounds sterling. The traffic, however, is sure to develop rapidly, and more expenditure will be required to cope with the increasing demand for power. The above sum does not include any expenditure for an automatic electric block-signal system. This will not be a necessity until the traffic increases so far that a 2½-minutes' service will no longer suffice; but it may be anticipated that it will not be long before this necessity arises.

14. The whole energy for the Inner Circle is brought down from Neasden to the Baker Street sub-station, and distributed from it as a control centre to the other sub-stations along the line. The following is the complete list of sub-stations, with the kilowatt converting capacity of each.

METROPOLITAN SUB-STATIONS.

	Number of units.	Rated power of each unit. Kilowatts.
Ruislip	2	800
Harrow	3	800
Neasden	3	800
Finchley Road	4	800
Gloucester Road	3	800
Praed Street	3	800
Baker Street	3	1200
Gower Street and King's Cross ...	3	1200
Moorgate Street	3	1200

Total, $18 \times 800 + 9 \times 1200 = 25{,}200$ kilowatts.

15. In these sub-stations the 11,000-volt three-phase current is reduced to 370-volts tension in oil-insulated self-cooling static transformers of 300 or 450 kilowatt capacity. These have 97½ per cent. efficiency at full load and 97 at half load. Three 300-kilowatt transformers serve each of the 800-kilowatt rotary converters mentioned in the above list, and three 450-kilowatt transformers serve each of the 1200-kilowatt converters.

A 300-kilowatt transformer stands 5 feet 8 inches high, and in plan its outside dimensions are 5 feet 6 inches by 5 feet 3 inches. The high-tension leads to the primary coils are brought in under the floor in earthenware ducts of 4 inches internal diameter, while the secondary is led off in a 3-inch-bore earthenware pipe. A 3-inch oil main runs the whole length of the building, from which a branch

leads to the bottom of each of the nine transformers. The high-tension switches and bus-bars are set in brick cells, and white marble is used for the low-tension switch-board.

The 800-kilowatt rotaries are 10-pole machines running at 400 revolutions per minute, the frequency being $33\frac{1}{3}$ per second. The 1200-kilowatt rotaries have each 12 poles, and therefore run at $333\frac{1}{3}$ revolutions per minute. An 800-kilowatt converter has 9 feet outside diameter of field, with an armature of 5 feet 6 inches diameter. Their efficiency ranges from 91 at half to 95 per cent. at full load.

The armature of these rotaries is drum-wound and slotted. Their field-poles are laminated and compound-wound, there being 10 per cent. over-compounding, or 10 per cent. rise of voltage from zero to full load. The potential difference between the segments of the D.C. commutator is 11 volts. The A.C. slip-rings are of brass with copper brushes. The machine is started and run up to synchronous speed by a small induction motor on its main shaft.

Fig. 178.—Section of 3-phase 11,000-volt Feeder Cable, Metropolitan Railway.

16. Fig. 178 shows the section of one of the three-phase high-tension feeder cables, the three leads being combined in one cable. The insulation is of rubber and paper with a lead sheath, outside which comes jute and steel-wire armouring. Over the armouring the diameter is about 3 inches, this varying but little with the size of the copper section. These cables are tested under water at 30,000 volts alternating, and are again tested at 22,000 volts after being laid in place. They are mostly laid in wooden troughs filled in with bitumen, but at special places are drawn through pipes. The copper sections are 0·10, 0·15, 0·20, and 0·25 square inches in different parts of the system. Four cables of 0·1 square inch section lead from Neasden to Harrow, and two from Harrow to Ruislip, while five go south from Neasden. Three large-sized cables of 0·25 square inch section enter Baker Street sub-station, and from this station four cables of 0·15 and 0·20 square inch section go to Praed Street and Gloucester Road, and four others to Gower Street and Moorgate Street.

17. The central station at Neasden is one of the largest in Great Britain. It is entirely equipped by the British Westinghouse Co., to whose engineers the author is indebted for much detailed information and many illustrations. Figs. 179 and 180 give plan and elevation of the building.

The main building is 321½ feet long by 102½ feet wide, with a central extension 89 feet long by 70½ feet wide for the economizers, beyond which stands the main chimney shaft, 15 feet inside diameter at the base, and 200 feet high. The base of this shaft is octagonal externally, of 26 feet diameter. The flue leading to it is no less than 28 feet wide. This flue is partitioned by a central wall into two parts, which may be used separately. The boiler-room, 53 feet wide, occupies one-half of the whole length. Here there are 10 Babcock and Wilcox water-tube boilers installed, with space left for 4 others. The 10 are to serve 3 turbines, the whole complement of 4 turbines requiring 14 boilers. The boiler pressure is 180 lbs. per square inch, and the evaporative power of each boiler is 20,000 lbs. per hour, the steam being superheated by 180° Fahr. Each boiler has 5730 square feet heating surface. There are four batteries of Green's economizer 4-inch tubes 10 feet long, each battery containing 440 tubes, or 1760 in all. For water supply, two artesian wells have been sunk a depth of 400 feet, from which ample water of good quality is obtained. An old existing pond has been extended, deepened, and embanked, so as to form a large storage reservoir and cooling tank.

Metropolitan railway sidings bring in coal, which is tipped from the waggons into a huge hopper 19 feet square. From this it is carried by a chain-and-bucket conveyer to the overhead coal-bunkers. The conveyer has an overhead horizontal run the entire length of the boiler-house, and returns along the basement underneath the stoking-floor in front of the boilers. From the bunkers the coal descends by gravity shoots to Roney's mechanical stokers by which the boilers are stoked. As the Roney grates are not yet well known in England, they may be here illustrated. Fig. 181 shows the front of a battery of water-tube boilers stoked by them, and Fig. 182 is a section of the grate. The grate is steeply stepped at an angle of 37 degrees, and ends in a horizontal dumping-grate. At the front top-end is a dead-plate played over by jets of hot air issuing from a cellular fire-tile hot-air chamber. A pusher-plate, reciprocated by an oscillating crank, draws the coal down from the hopper on to the dead-plate. The rate of feed can be regulated by the feed-wheel, which alters the throw of this pusher-plate. The grate-bars are rocked from the horizontal position shown in Fig. 182 into an inclined position, in which their front edges dip downwards by 30 degrees. The form of grate-bar used is shown in Fig. 183. It is made in two parts, the top plate, which carries the coal, being

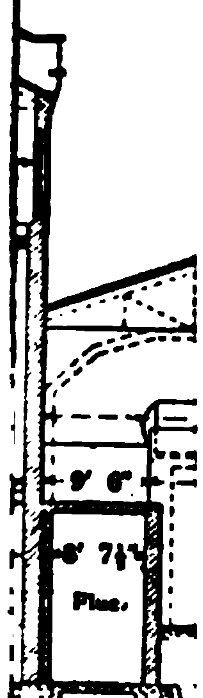

9' 6"
8' 7½"
Flue.

FIG. 181.—Boilers with Roney Mechanical Stokers and Coal and Ash Machinery.

bolted on the vertical web, and therefore easily renewable. The ribbing of the under side of this plate serves three purposes, to strengthen the plate, to prevent its overheating by the cooling action of the air passing between the ribs, and to warm this air before it gains access to the coal. The angular rock of the bars can also be regulated according to the class of fuel used by the sheath-nuts upon the eccentric which oscillates the rocker bar.

The ashes are raked by hand into the tubs of the conveyer, which is alternately used for filling the bunkers with coal and for the removal of ash and clinker.

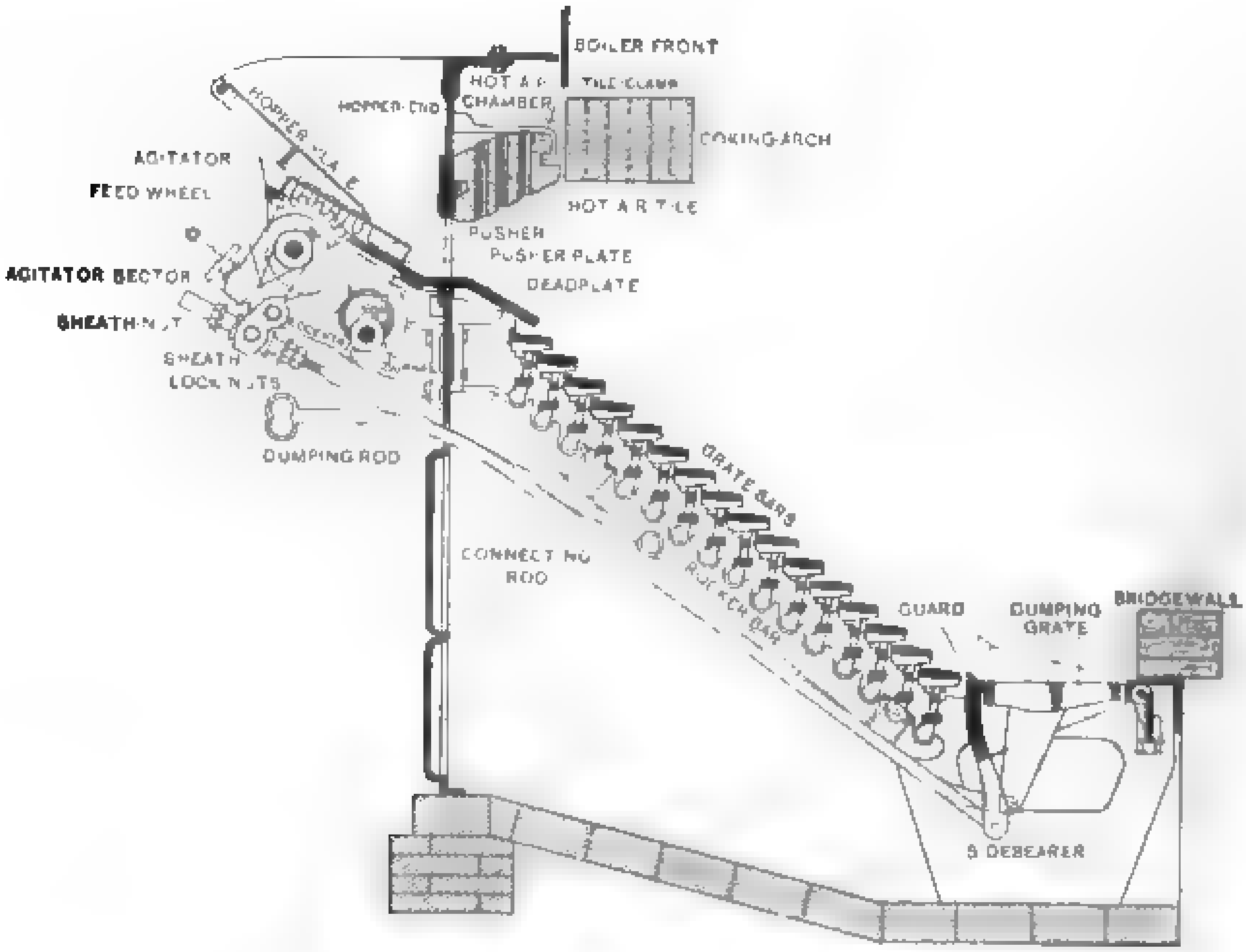


Fig. 182.—Section of the Roney Mechanical Stoker.

18. The generators are driven by duplex steam turbines which have an exhaust at each end of the casing. Each exhaust pipe is 40 inches in diameter, and the pair for each turbine join together in one pipe of 54 inches diameter. This pipe rises vertically about 34 feet, and, at this height above the water in the hot well, discharges into the large circular disc-shaped chamber of a "barometric" condenser. Here it plays upon the surface of the condensing water, which enters this chamber in horizontal jets, and which is pumped up to this level by an 18-inch Gwynne centrifugal pump driven by

a 10 + 18 inches by 10 inches compound engine. Each turbine is served by a separate condenser and set of pumps. This condenser is of the Alberger Co.'s design, and its normal capacity is 66,500 lbs. of steam condensed per hour, but can for short periods work up to 110,000 lbs. per hour, when, however, the vacuum obtained may fall as much as 2 or 3 inches. The normal vacuum is 27 inches mercury with circulating water not above 85° Fahr. The mixed circulating water and condensed steam descends by gravity through a vertical pipe to the hot well. The air that separates from the condensing steam gathers in the conical head of the condensing chamber, and

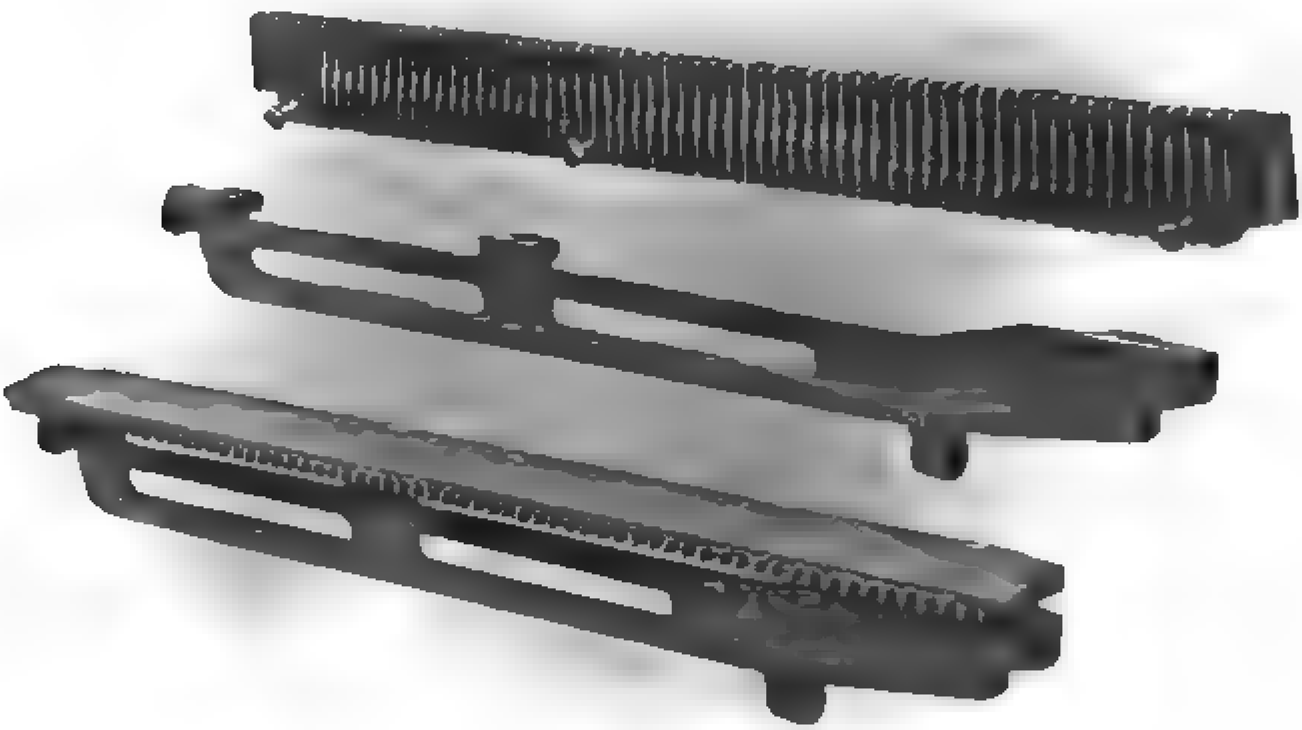


FIG. 183.—Roney Renewable Fuel-plate.

is there cooled by a finely divided spray from the circulating water supply. From here this cooled air and some steam mixed with it are drawn off by a two-stage air-suction pump of Alberger design. The cylinders of this pump are 10 inches and 24 inches diameter by 24-inch stroke. In the barometric form of condenser the good action of this air-pump is very important, the good or bad vacuum obtained depending largely upon it. Only a very small fraction of steam passes through these pumps, the bulk being condensed, and flowing away by gravity with the circulating water. The advantage of the system is the avoidance of the use of pumps to extract the water from the condenser, the suction-pump having to deal only with

a small quantity of gas and vapour. The "dry-vacuum" pump, as it is called, for each Neasden turbine takes 55 horse-power to drive it at normal load.

19. The hot well which receives the discharge from these barometric condensers forms a wide concreted trench running along the north wall of the station outside the building. From here the water is pumped to the tops of "Donat" cooling-towers by 16-inch diameter "Worthington" hot-water pumps driven by 11 + 19 inches by 11 inches compound steam-engines. There are two cooling-towers for each turbine. Each tower is said to pass over 4,000,000 lbs. of water per hour, cooling it from 180° to 80° Fahr. Each tower is simply an immense stack of thin timber slats set in notched purlins in horizontal tiers. The slats slope about 45 degrees to the horizontal, alternately right and left hand, in successive tiers. Each tower is some 30 feet square in plan and about 60 feet in height, and has some 200 tiers of such slats. The entering water runs along the roof in two large trough channels made of stout plank, which are perforated with many small holes, through which the water falls in jets upon the upper tier of slats. This deflects and scatters it in rain, and as it falls further it impinges upon the many lower tiers of slats, being scattered again in each impact. At the base is formed a shallow tank, from which the water flows away in channels to the reservoir previously mentioned. Each tower is strongly braced to make it a substantial structure capable of withstanding a gale of wind. As all the slats are kept constantly wet so long as the condenser is at work, they are said not to rot, and to have a life of many years.

20. Each generator has a normal power of 184 ampères in each phase at 11,000 volts on a non-inductive load. It is 4-pole, and runs at 1000 revolutions per minute, direct coupled to the steam-turbine, thus giving the frequency $\frac{2 \times 1000}{60} = 33\frac{1}{3}$ per second. Its efficiency runs from 94 to 96½ per cent. The inside diameter of the external armature is 6 feet, and the diameter over the pole-faces of the rotating field is 5 feet 8 inches, thus leaving a 2-inch air-space. The field is 3 feet 9½ inches in axial length, and weighs nearly 30 tons, the weight of the whole alternator being over 90 tons. The pole-pieces are slotted on their edges, as seen in the photographic view (Fig. 184), but are not otherwise laminated. The slots containing the field winding are 4½ inches by 1½ inch. The shaft is 16 inches in diameter at mid-length, with journals 11 inches diameter by 40 inches long. The length of the generator over all is 17 feet. Figs. 184 and 185 show its rotating field and fixed armature separately.

21. There are only two exciter dynamos installed, each independently driven by a small compound Westinghouse steam-engine. These are compound-wound for 125 volts. They run at 275 revolutions per minute, and give 100 kilowatt output. Each is independently able to excite all the main generators if required to do so. There is also a 100-kilowatt 440-volt 3-phase auxiliary generator,

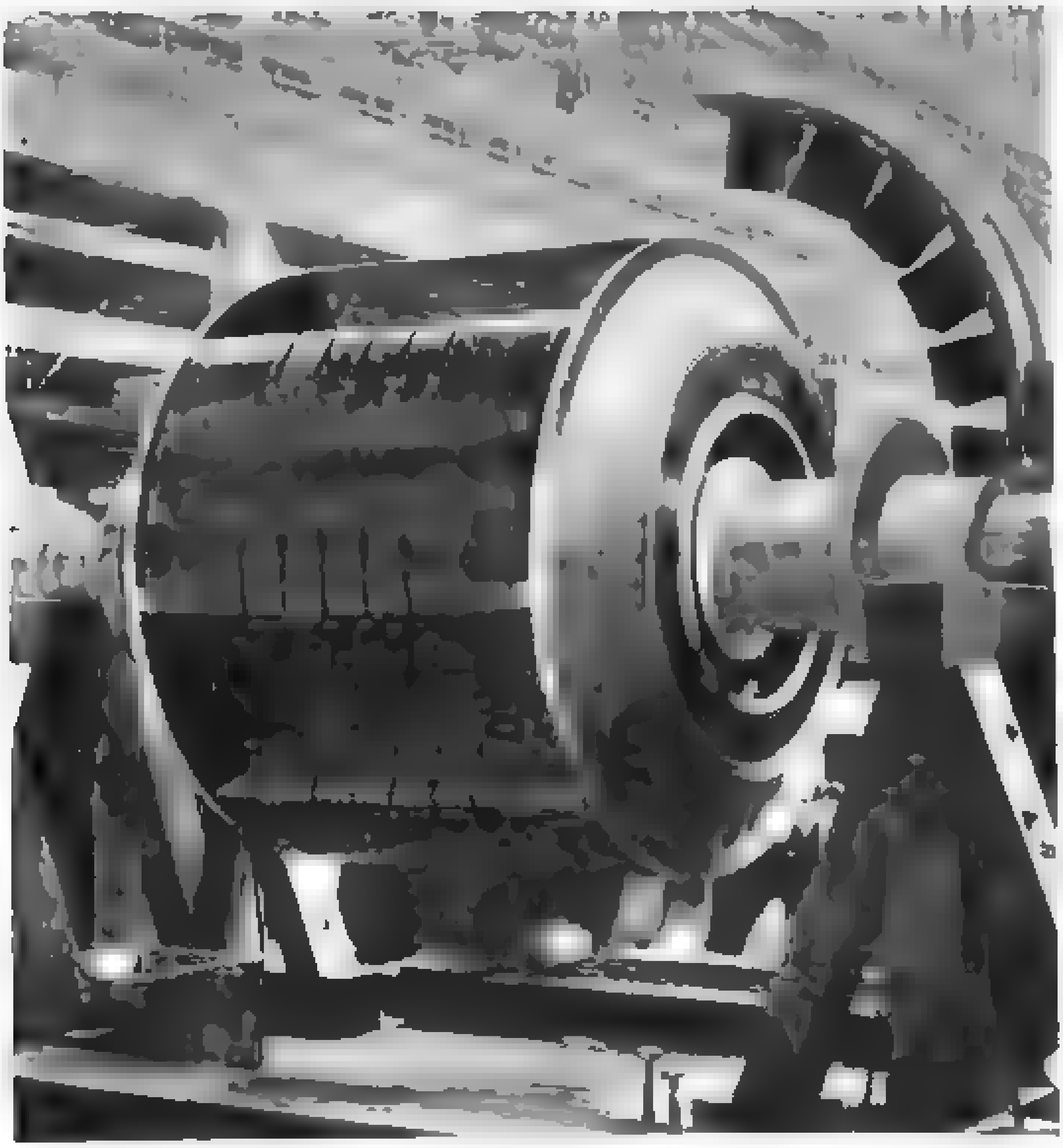


FIG. 184.—3500-kilowatt Westinghouse 3-phase Alternator, Internal Revolving Field.

running at 286 revolutions per minute, which supplies energy to various central station induction motors to drive the coal conveyer, the economizer scrapers, the travelling cranes, and other odd work.

22. The steam-turbines driving these alternators are of 5000 horse-power. They are the largest yet made, with the exception of the 7000 horse-power machines in the Chelsea generating station. Both are made by the British Westinghouse Co., of Trafford Park,

Manchester, and are of the "Parsons-Westinghouse" design. Figs. 186, 187, and 188 give outline views of these machines, and Fig. 189 gives some idea of their internal construction, while Fig. 189A is a good outside view of turbine and generator together. The outside diameter of the casing is only 11 feet, and the total length of casing only 13 feet. The total length over the bearings is 28 feet.

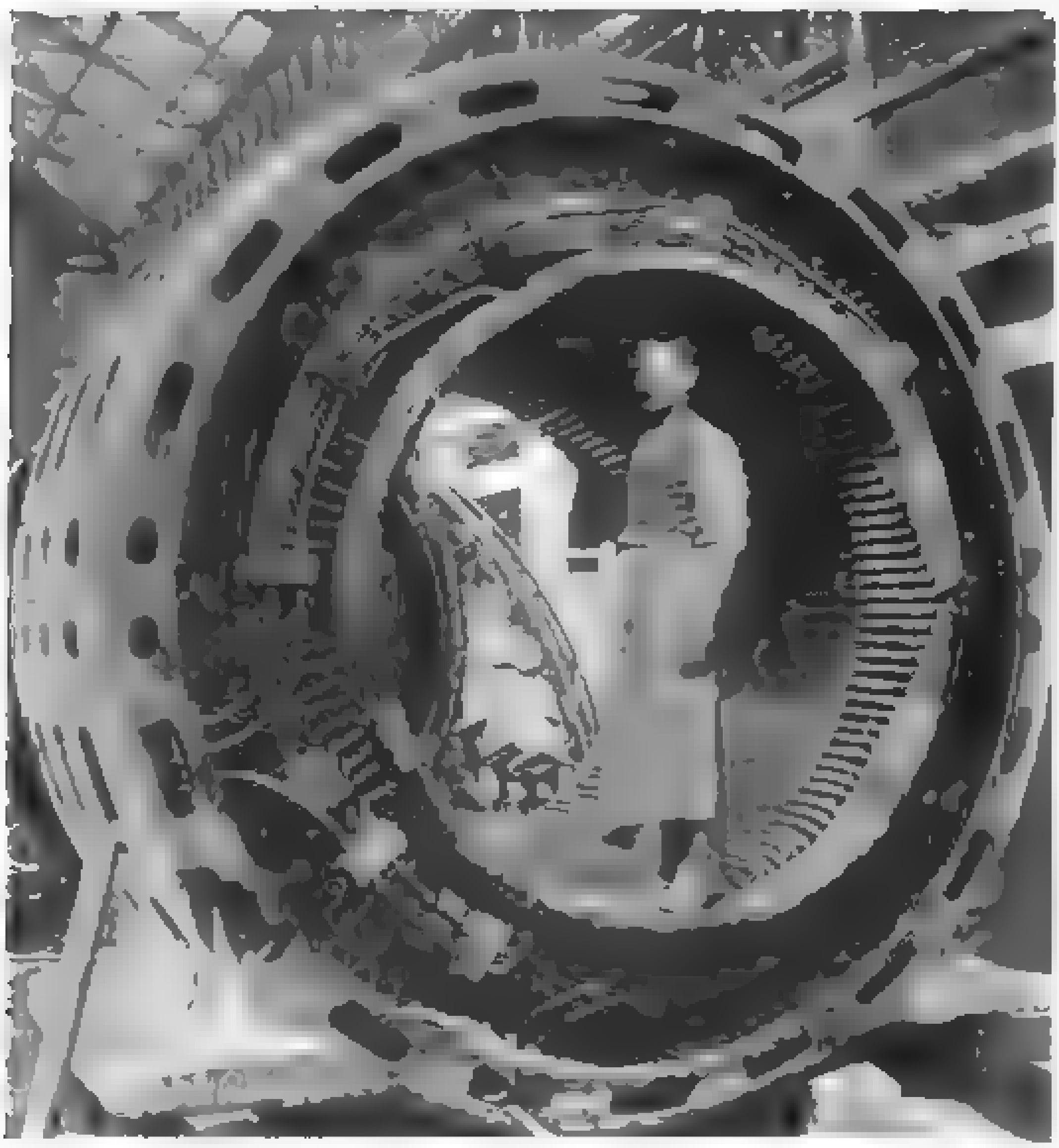
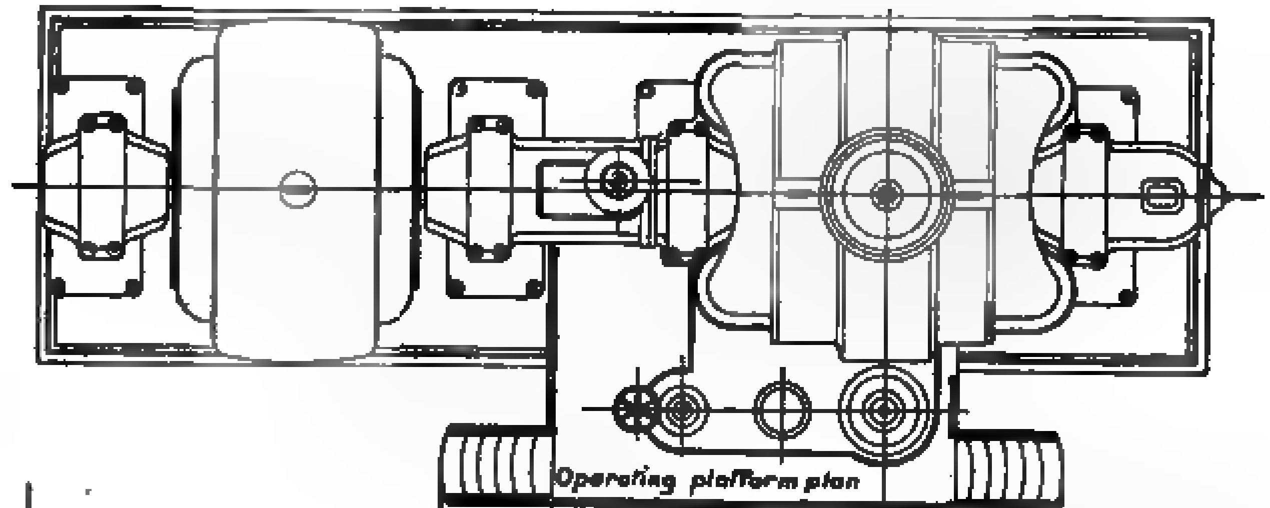


Fig. 185.—3500-kilowatt Westinghouse 3-phase 11,000-volt Alternator, External Stationary Armature.

They are guaranteed to consume not more than 17 lbs. of steam per kilowatt-hour at full load, and, although they have not been yet tested at the time of writing, the manufacturers expect that they will do better than the guarantee, and preliminary trials at small power prove that they will at least give more than the specified horse-power.

They are duplex; that is, the steam enters at the centre of the length of the casing, and the flow splits here, the halves going

Fig. 188.—Plan.



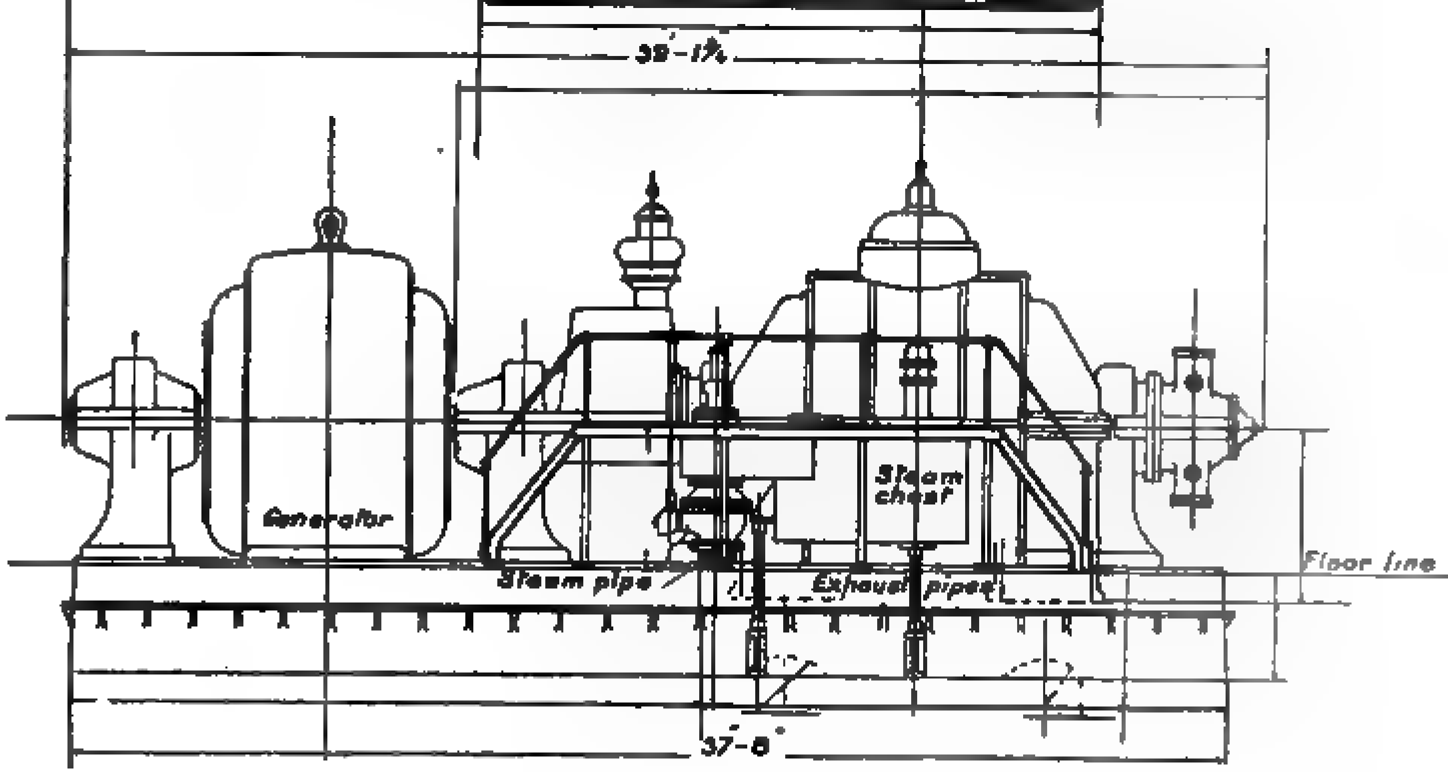


Fig 186.—Elevation of Westinghouse Turbo-generator.

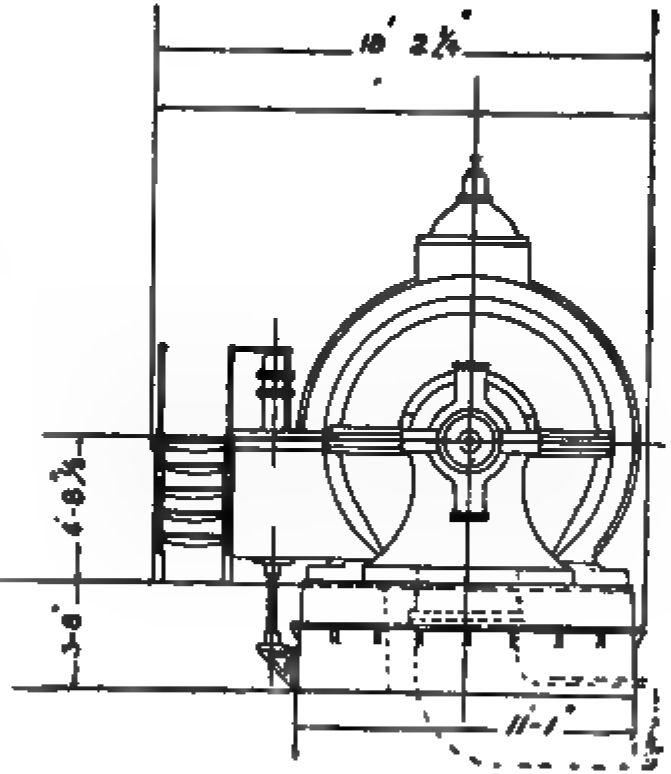


Fig. 187.—End View.

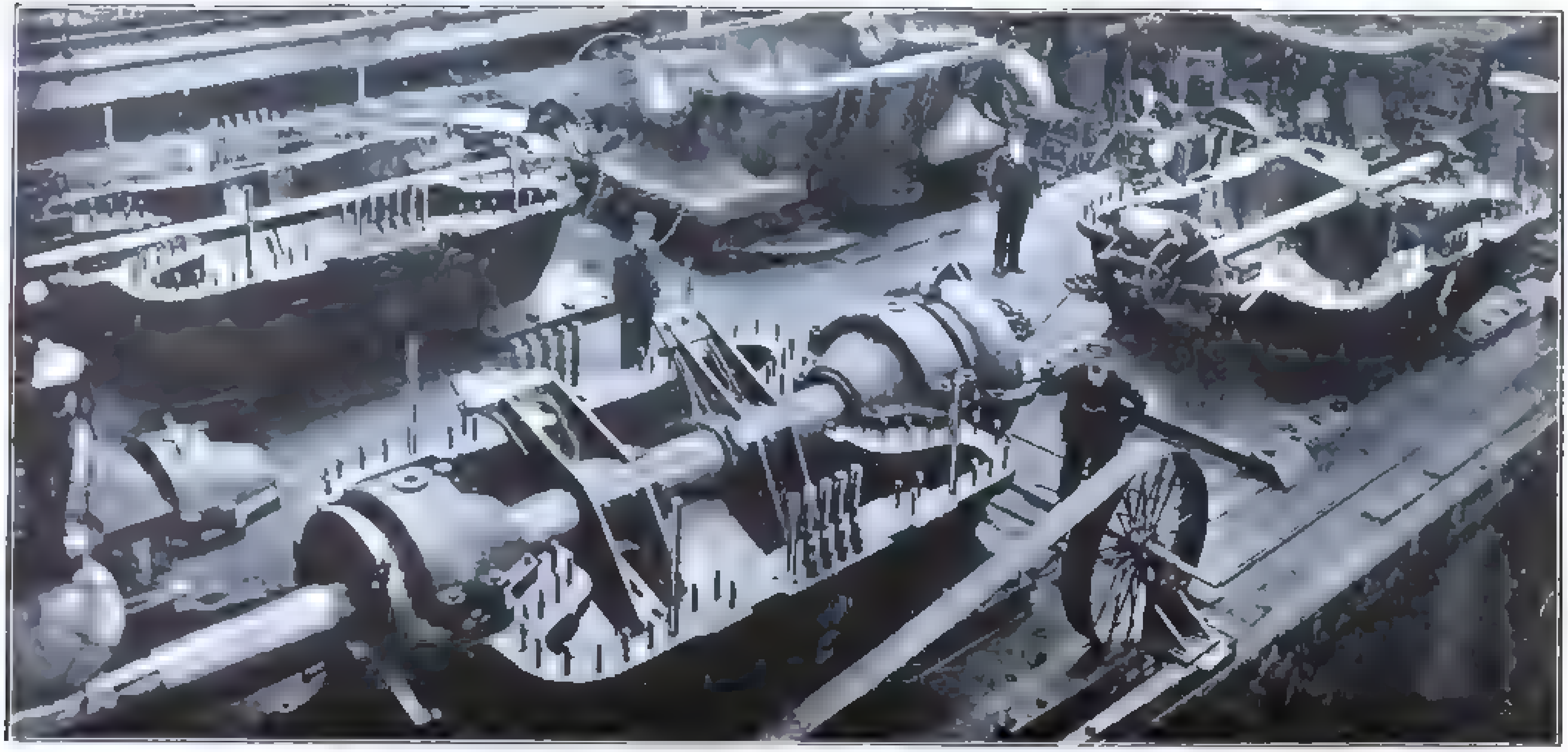


Fig. 189.—Westinghouse Steam Turbines during Construction.

through two identically reverse sets of blades in the two opposite directions. Thus the end thrusts are approximately balanced in the shaft itself, and do not come upon the collar bearings, and also the two stuffing-boxes at the two ends of the casing are both exposed to exhaust steam inside. They are kept tight against in-leakage of air from the outside atmosphere by blowing a small quantity of steam of pressure a little above atmosphere into a ring groove in the middle of the length of the gland. Again, the bearings are remote from all parts filled with high-temperature steam, only exhaust steam coming within near range of them.

The turbine, therefore, consists of two reverse turbines, both, of course, driving in the same rotational direction. In each half there are 19 crowns of rotating-blades, and 19 crowns of guide-blades fixed to the internal wall of the casing. The steam passes in succession through all these. The 19 crowns are set in 5 groups of different construction, blade-size, and diameter. The first group, called the "nozzles," has only one ring of rotating-blades, which are made large and very strong to take the first impact of the steam rush from the entrance nozzles, which are spaced equidistantly round the circumference. The next group has 3 crowns of rotating-blades; the next 7, and the last two groups 4 in each. The pressure falls largely in the first four crowns, and probably very little work is actually done in the last eight. Until the turbines are tested under full load, however, nothing with certainty can be predicted as to the precise action of the steam in passing this series of wheels.

23. As seen in the plan (Fig. 179), the switchboard galleries occupy the whole breadth (42 feet) of the machine-house throughout a length of 90 feet at one end of it. It is really a three-storey switch-house. The ground floor is mainly devoted to the feeder bus-bars to the sub-stations, and to hand-switches for the various working circuits for power and lighting in the central station itself. On the first floor are placed the bus-bars and the high-tension main switches of the main generator circuits. In the comparative quiet of the top floor stands the master control switchboard close to the edge of the gallery, from which a complete bird's-eye view over all the working plant, with the exception of boilers, condensers, and pumps, is obtained.

There are two triple sets of main generator bus-bars. On the main cable from each generator is placed a triple-pole high-tension oil-switch. Beyond this the cable branches to lead to the two sets of bus-bars, and in each branch is interposed another similar 3-pole switch. Between each of these latter and its own set of three bars is placed a 3-pole knife-edge switch, whose purpose is to cut off a generator and its oil-switches from the bus-bar in order to examine and, if necessary, repair an oil-switch while the bus-bar is alive from

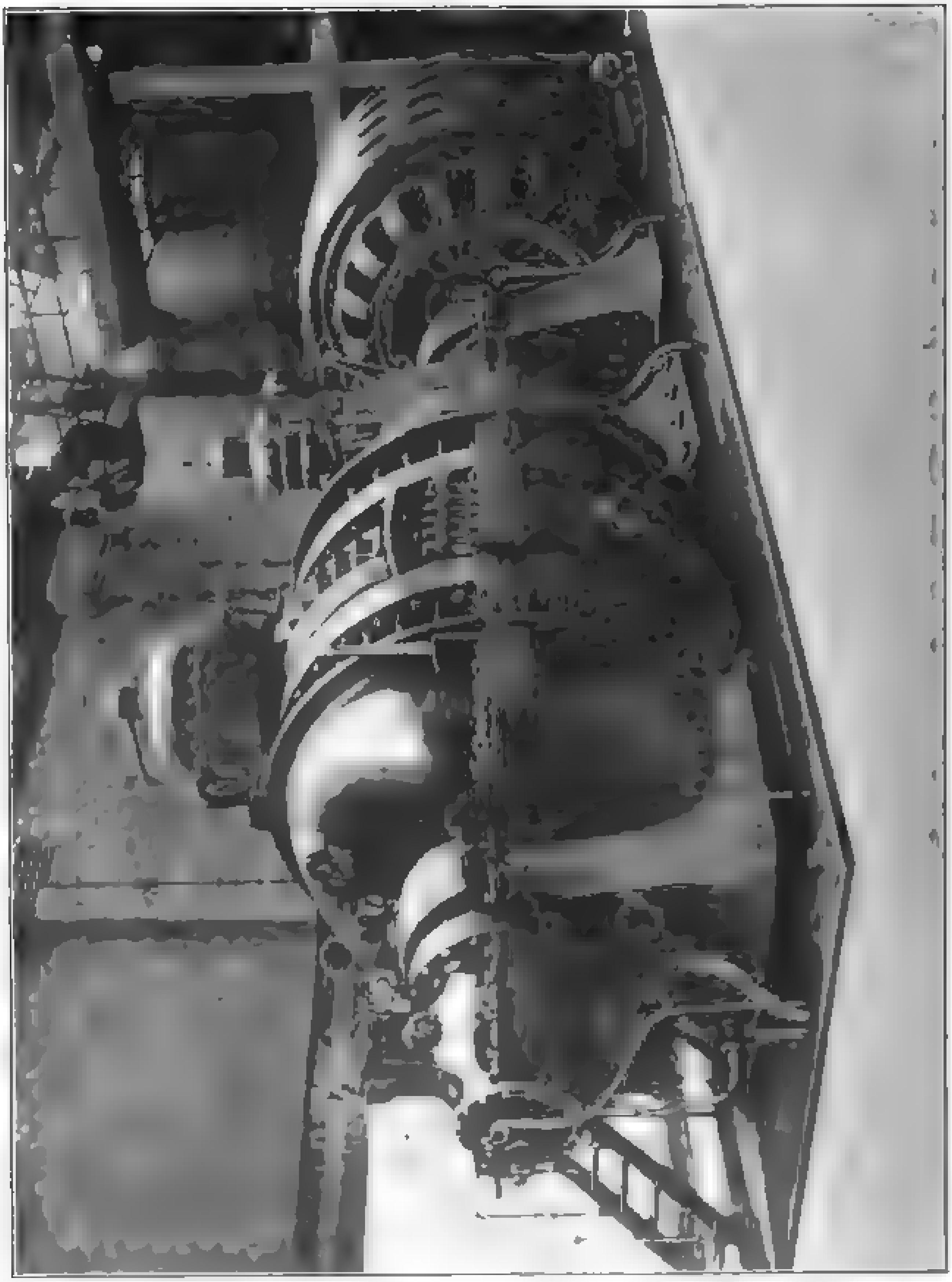


FIG. 180A.—Westinghouse Steam Turbine and Alternator at Neasden Power Station.

other generators. The oil-switches are the normal working main switches.

Between the bus-bars and the feeders there is a similar arrangement of switches, enabling each feeder to receive energy from either bus-bar separately or from both conjointly.

24. The whole of the generator, exciter, and feeder circuits are controlled from a small marble desk "control-board." The relay currents, by means of which the main switches are moved from the control-board, are derived from the exciter sets, but these currents do not themselves pass the control-desk. This table is shown in Fig. 190.

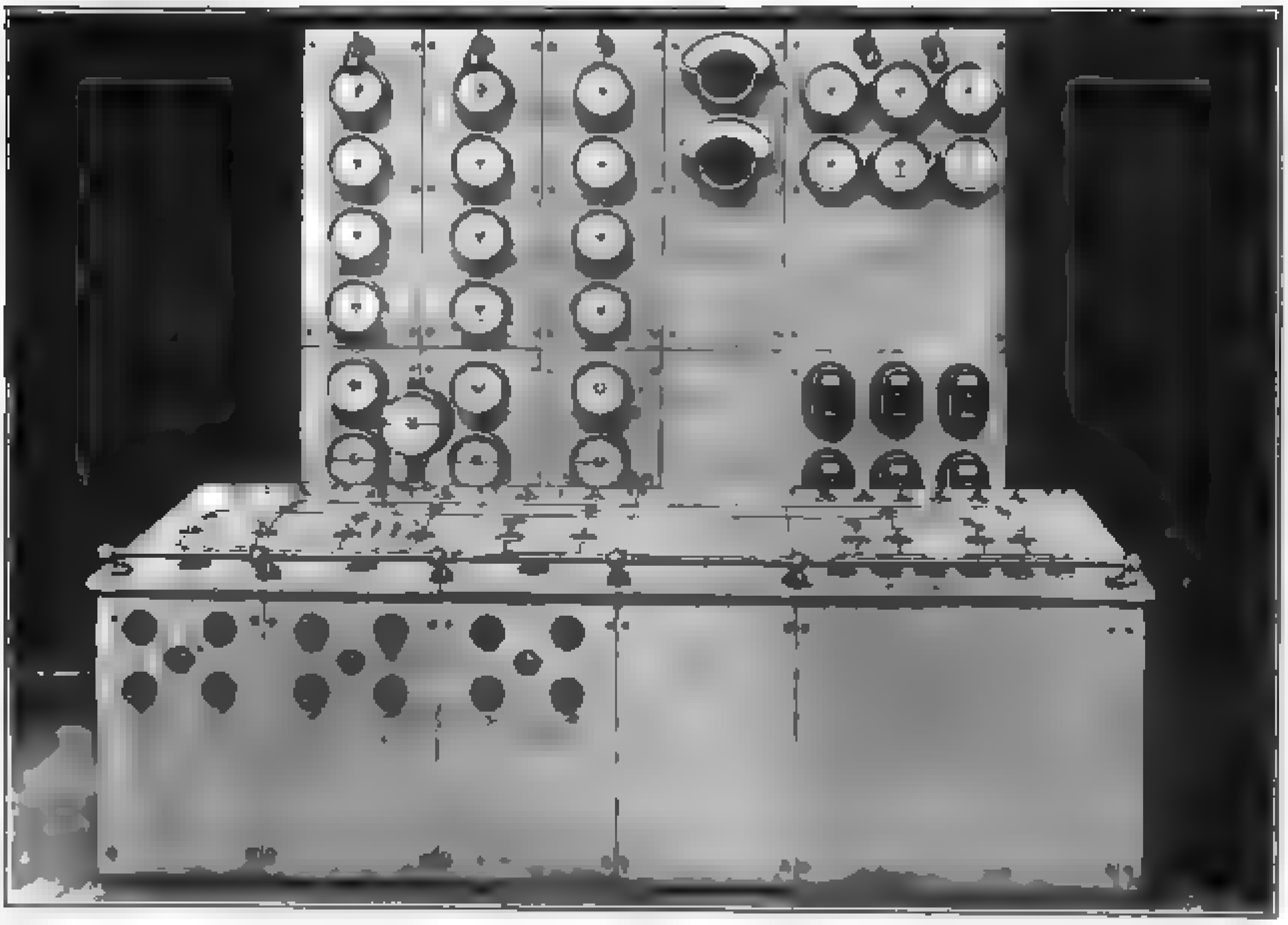


FIG. 190.—Control-board, Neasden Power Station.

It is only 10 or 12 feet long, and none but very small currents of a few volts tension come to it. On its sloping surface is set out in thick black lines, made with strips of ebonite, the main scheme of the connections. In Fig. 190 only three generator panels are shown equipped, because the fourth generator was not installed when the photograph was taken. A panel upon the desk is left blank for this fourth unit. On the diagram, in the place of each switch there is a small rotatable disc marked with a black bar across it and carrying a tiny signal lamp. An electro-magnet beneath the disc always sets it so as to show whether the main switch, of which the disc is the

image, is open or closed. The lamp lights up whenever the switch has been opened by any of the automatic safety appliances which guard the installation in various ways.

This table also carries, on vertical slabs erected at its back edge, a few low-tension instruments, such as the synchronizer showing when two generators may be thrown in parallel on one bus-bar. The speed of each turbine and generator can also be regulated from this table by an electrical control acting on the governor. This regulation is effected by screwing a counter-weight along a lever acting upon the "monkey-brass," the screw being rotated by a small electro-motor.

The manipulation of the control-board is effected by the small handles seen on the vertical front slabs of the desk, the horizontal table being wholly devoted to the signal indications of the results of this manipulation.

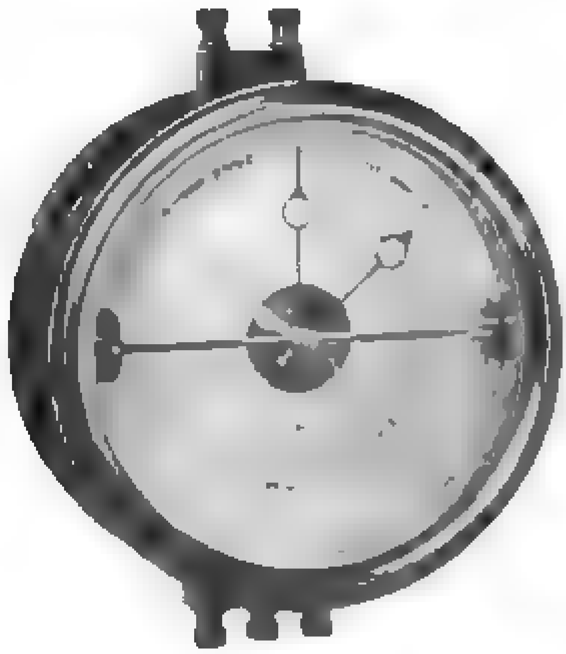


FIG. 191.—Switchboard Synchronizing Indicator.

25. Fig. 191 shows the external form of the instrument used for synchronizing, a very beautifully simple form as compared with the somewhat clumsy lamp devices mostly used until recently. The instrument spindle carrying the short dial-finger is given a slow right or left hand rotation according as the speed, and therefore the frequency, of the generator to be thrown in parallel is greater or less than that of the generator already on the bus-bar. The deflection of the finger, in fact, really measures the phase difference between the two machines; and when the finger stands steady at zero it indicates that the two machines are in phase with each other, and also that they are running at the same speed.

Not far from the control-table, and within sight of it, stands the bench containing the field rheostats of the main generators. The contact arm of each rheostat is moved round by a small motor and worm gear, the current to drive this motor forwards or backwards being switched at the control-table. Fig. 192 shows the vertical marble slab carrying the ring of resistance contacts, and this motor gear driving it, while Fig. 193 shows the field-switch, which is mounted immediately over the above on the same bench, and which is also electrically operated from the control-table.

26. An important instrument on the switchboard of modern large

generating stations is the "Time limit relay." The inside of one of these instruments is shown in Fig. 194. Its object is to delay the operation of a safety cut-out switch. A short circuit takes *time* to do serious harm, the harm being nearly always over-heating, breaking down insulation, and setting fire to insulation or other inflammable parts. The "time-limit" prevents the protective cut-out switch acting with unnecessary quickness; it prescribes the exact time during which the short-circuit may continue before it is automatically broken. The most important function of this device is to differentiate between branches and sub-circuits, and prevent breakdowns in these from involving stoppage of the whole system of which these are isolated parts. This is effected by setting the time-limit instrument protecting the branch so as to operate the cut-out on this branch more quickly than the time-limit instrument set to protect the whole system, or the next superior part of the system.

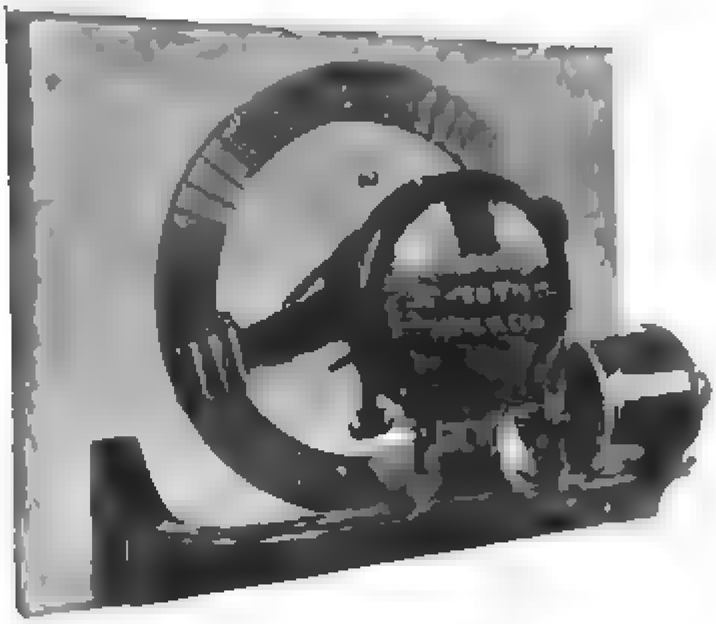


FIG. 192.—Generator-field Rheostat, Motor-driven.

The instrument shown in Fig. 194 is an air dash-pot mechanism. The central vertical casting contains the operating solenoidal electro-magnet, the casing forming itself the outside limb of the magnetic circuit. From the top of this casing projects a bracket, from which hangs by a pin-joint the air cylinder of the dash-pot. The piston-rod of the piston in this cylinder projects downwards, and is pinned to the extremity of a lever pivotted on a lug cast on the lower end of the magnet casing. The weight of this lever is balanced by an adjustable counter-weight, but the weight of the solenoid core rests upon the lever so as to depress it and draw the piston out of the dash-pot cylinder. This piston thus rests at the lower end of the dash-pot so long as the solenoid is not excited, this arrangement keeping the dash-pot clean by the exclusion of atmospheric dust, etc. When the solenoid is excited, it pulls up the core and the counter-weight drives the piston up the dash-pot cylinder at a time rate which may be adjusted either by adjusting the position of the counter-weight, or by the setting of an air bye-pass valve. The end of the lever carries a contact-plate, making contact with two fixed spring contacts for the passage of the relay current which operates the cut-out. The spring

contacts can be adjusted in level by a thumb-screw on the dial-plate outside the instrument case, thus regulating the length and the time of the air-braked stroke in the dash-pot before cut-out contact takes place.

27. On the first floor of the "switchboard," that is, on the gallery below the master control-desk, are the main bus-bars and their connections to the generators on the one hand and to the feeders on the other.

These are all laid in isolated brick cells or channels arranged on opposite sides of brick walls. On the one side lie in tiers the horizontal channels running the whole length of the "board" and containing the bus-bars. On the other side the channels run upwards and contain the switches and the terminal connections. Where no contacts are made, all these channels are open fronted, leaving all the connections in full view of the attendants. But where switches open and close the circuits, the channels are covered by sheet-iron doors, each easily removable by hand, and all of them metallically connected to earth by the channel-iron framing on which their lower edges rest, and by their latch-clamps.

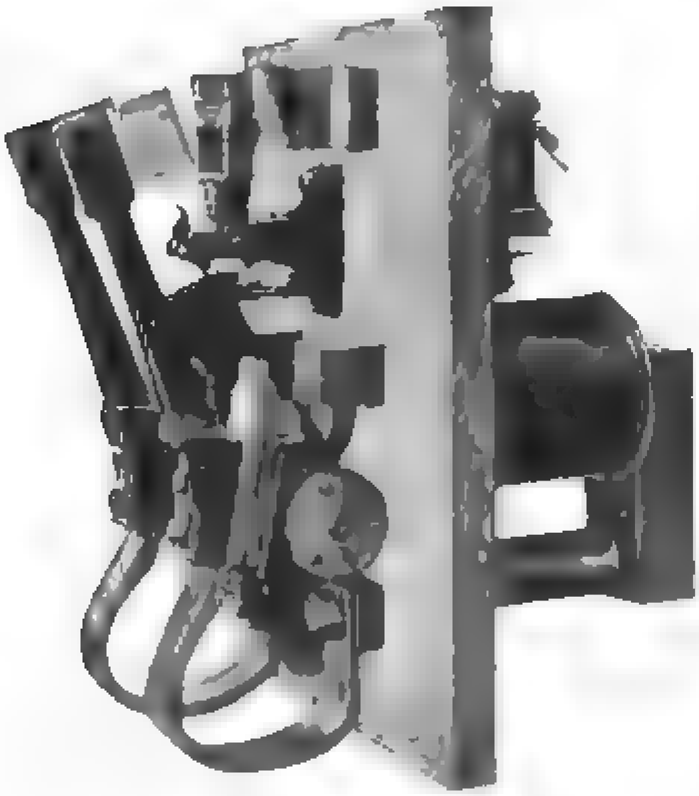


Fig. 193.—Generator-field Switch, Magneto-electrically operated.

Fig. 195 shows one of the main oil-switches. The three double poles are in channels separated by brick walls. The oil in each switch is contained in a vertical sheet-steel cylinder with cast-iron top and bottom ends, and lined thickly inside with insulating cement. In each of the three switches there is a double break. The positive and negative terminals are brought in through the top cover of the oil-cylinder through white, well-vitrified porcelain insulators. The whole is hung from a soap-stone slab lying over the brickwork partitions and under the cast-iron base-plate of the working mechanism. Into each oil-cylinder descends a stout ash rod, upon the lower end of which is fastened a ⊔-piece of copper. The flat upper ends of the two legs of this piece make contact with the flat-ended terminals when the wooden rod is drawn upwards. In the fixed terminals there are inserted central plugs, which enter fitting holes bored in the upper ends of the ⊔-piece, so

that on opening the switch the flash is confined to these plugs, which can be readily and cheaply renewed. The break takes place under oil of special insulating quality. The lining of the oil-tubes is formed so as to reduce the quantity of oil required to fill the vessel up to the level of the contact points to a minimum.

The three wooden rods are pinned to a horizontal cast-iron crosshead, which is guided to move parallelly up and down by an ordinary

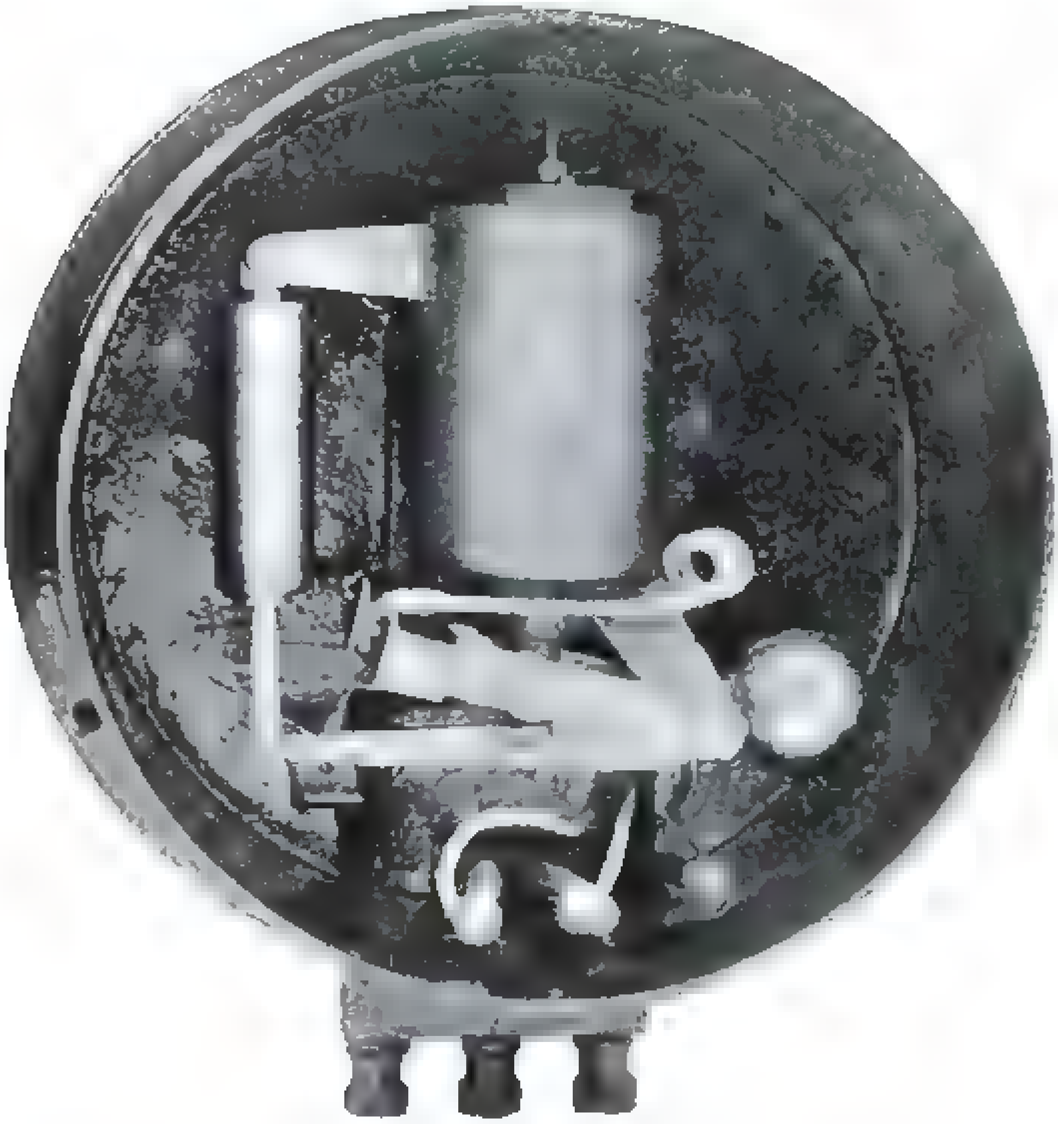


FIG. 194.—Time-limit Relay.

parallel link-motion. It is lifted by a lever pivotted on the cast-iron frame, and pulled down at the end of its shorter arm by two electro-magnets through chain gear. The electro-magnets are helped through the early part of their working stroke by two powerful springs. This makes the first part of the lift quick, but in its last part, immediately before contact, the springs act with much diminished leverage. When the contact is made, the switch is locked by a toggle-link falling into place under the crosshead. When the switch

is opened, the relay current from the control-board excites an electromagnet, which causes a hammer to strike this toggle-link out of place so that the support of the crosshead collapses. Not being now supported by the lifting-magnets (as these are not now excited), the weight of the crosshead and the rods causes them to fall suddenly, giving a quick break to the six main-switch contacts. In the open position the wooden rod interposes a good insulating screen between the two terminals in each switch.

28. A small 2-pole double-throw knife-switch, which is thrown over by the motion of the above main linkage, makes and breaks the contacts for the tripping and signalling circuits. Whenever the switch opens, the open position is signalled to the control-desk. If it be opened automatically without the interposition of the control engineer, the signal lamp on the control-desk is lighted up.

At the control-desk the operating handle has three positions—"open," "closed," and "off." If the engineer turns it to "open," the handle remains in this position when the hand is removed from it, being held in it by a light spring, and a shunt of the exciter circuit trips the main switch gear and opens its three poles; this without lighting the lamp on the control-board, but signalling by a 90 degrees turn of the small disc on the table-diagram that the switch is open. This signal is not given until the trip has actually been effected; it comes through the closing of the knife-switch in Fig. 195.

If the engineer moves his handle to "closed," and holds it so until he gets a signal, he thereby excites the magnets of Fig. 195, closes the three poles of the switch, and opens the knife-switch, whereupon the signal current that has kept his signal-disc cross-barred is interrupted, and the armature under this disc is drawn by a spring to zero position, in which the bar on the disc lies in alignment with the leads to and from the diagram-image of the switch. If he now removes his hand from the operating handle, this flies of its own accord to the position called "off," and remains there. In this position the whole electrical mechanism is in readiness to be tripped automatically by an excess current in the mains.

29. This automatic tripping is effected by what is called an "overload relay." It is seen near the top of Fig. 195, and again to larger scale in Fig. 196.

In this, above two double-pole electro-magnets, whose cores are made up of thin strips of soft iron, are pivotted two sectors of aluminium plate, which have considerable area as compared with their weight. Each sector hangs between the two poles of one of the magnets. When these sectors are drawn together they make contact for the tripping circuit which opens the main switch. The neutral position of each sector is set by a small adjustable counterweight consisting of two nuts upon a screwed wire projecting as a

horn from the top of the sector. The magnetic field is disturbed by current through a short-circuited turn of copper laid round the

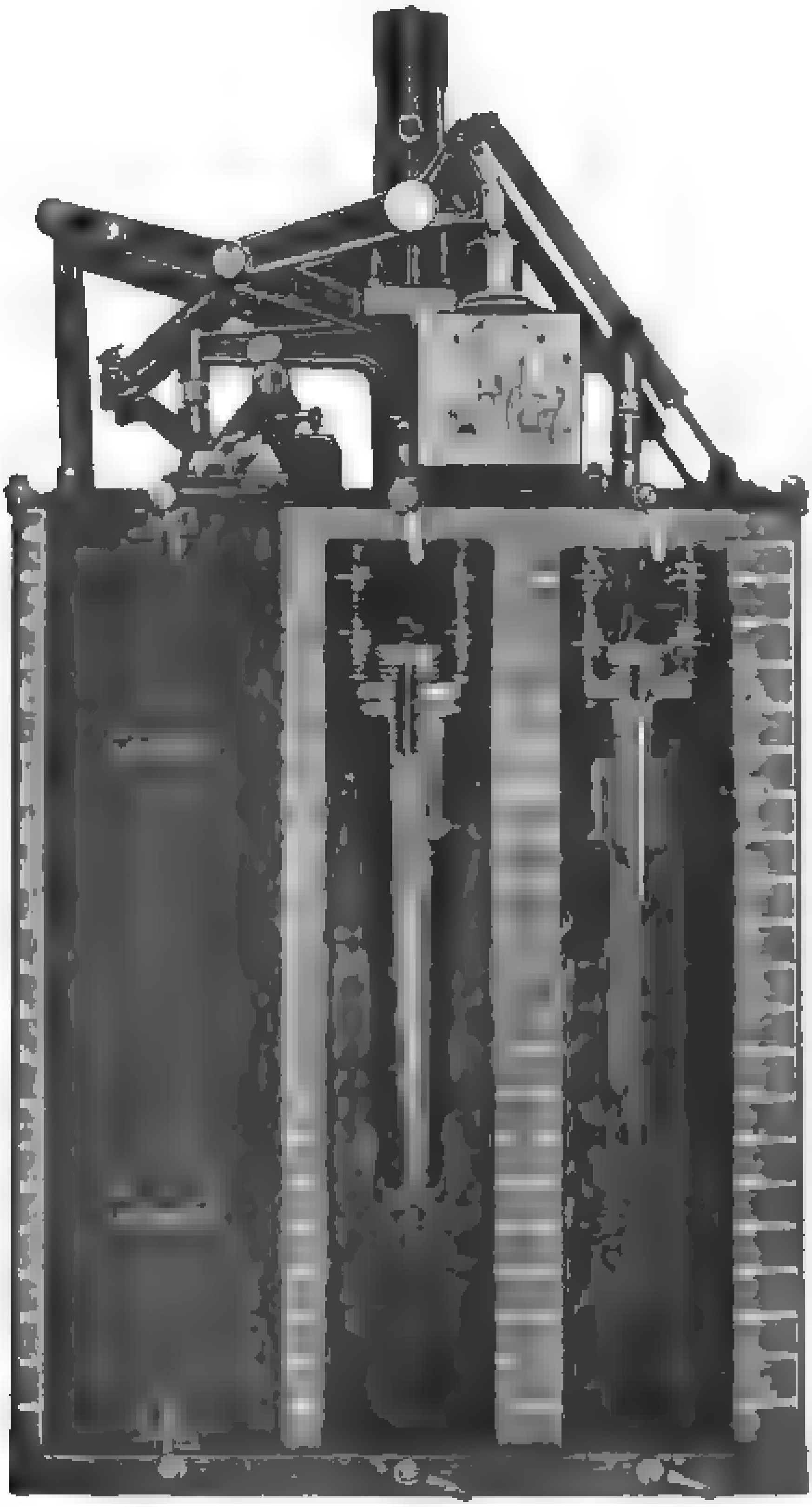


FIG. 195.—Main 3-pole High-tension Oil-break Switch.

magnet, this disturbing current being derived from the main current by a small triple step-down-transformer. The shifting of the field due to this disturbing influence moves the aluminium sector by inductive

action, and when the disturbing current reaches the prescribed limit, contact is made, the main switch is tripped and opened, and at the same time the signal lamp is lighted up on the engineer's control-desk.

30. The Chelsea Generating Station was completed a few weeks later than that at Neasden. It is very much larger, and in point of size and equipment will be probably the finest yet erected anywhere in the world. It also is being equipped electrically and with steam turbines by the British Westinghouse Co., except that the switchboard instruments are of British Thomson-Houston make.

This station is to supply power and light to the whole of the Metropolitan District lines, to the Earls Court–Brompton–Piccadilly line, and to the Waterloo–Baker Street and the Charing Cross–Hampstead lines.

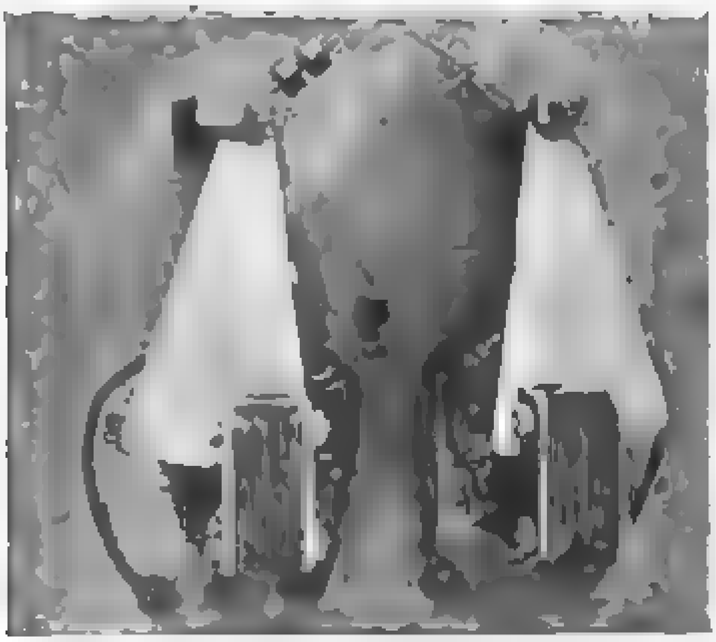


Fig. 196.—Overload Tripping Relay.

In it there are being laid down 8 turbo-generators, each of 7500 indicated horse-power, or 5500 kilowatt electric output; and beds are being laid for two more such units, which, it is anticipated, will be needed within a short time. The works are thus laid out for 75,000 horse-power.

The works cover 3⅜ acres of land. Within their boundaries has been built a new dock on the north bank of the Thames for the unlading of coal and other supplies. From the barges the coal is picked up by two 1-ton travelling grab-cranes, which span the dock from side to side. From these the coal is deposited upon a very large belt-conveyer. This latter tips it into an immense hopper, from which two chain-and-bucket elevators carry it to the top of the building. Each of these elevators is driven independently by a 30 horse-power induction motor placed at the top. The buckets of the elevators deliver the coal on to two horizontal belt-conveyers of wire-woven canvas and rubber band, stretching the whole length of the building, and discharging the coal into the overhead bunkers. These belts travel at the speed of about 550 feet per minute. The storage capacity of the bunkers is 15,000 tons, which is three weeks' consumption for the whole plant. The capacity of this machinery is 1500 tons per day, and it is all electrically driven.

At this end of the works stands the isolated tower containing the large oil-cooling tanks, and a water-reservoir tank holding 180 tons of water. Artesian wells have been bored, and yield a considerable supply of good boiler water.

Four chimney stacks have been built. The lower portions of these stacks, octagonal in shape and 75 feet high, have been built by an English firm, Mayol and Haley; but the upper 200 feet of height, round in section, and 19 feet internal diameter at the base, have been completed by a German firm.

The main building is a steel frame filled in with brick and terra-cotta, and with concrete floor and roof, the turbine and generator floor alone being of checkered steel plates. It is 453 feet long by 175 feet wide, and stands 140 feet high. Above the ground floor there are three upper floors and the coal-bunker gallery. Fig. 197 gives a section of this station, and Fig. 198 is a plan of it.

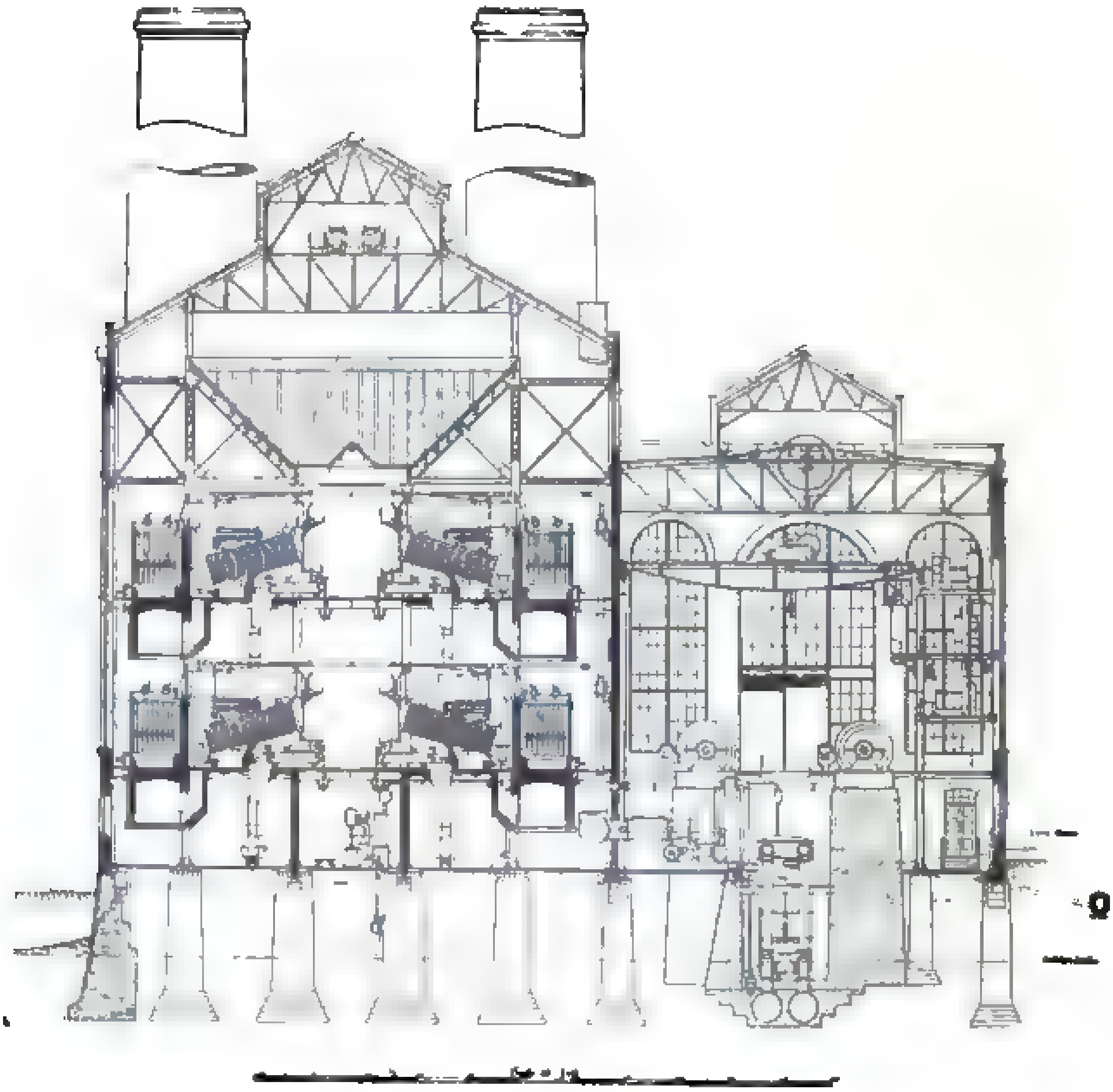
31. Sixty-four Babcock and Wilcox boilers, each of 5212 square feet heating surface and 19,000 lbs. per hour steaming capacity, have been installed, and space in the present building for 16 more similar boilers is provided. In plan these boilers are arranged in two rows, face to face with a 10-feet-wide stoking gallery between them, and they are built in two stories, 16 boilers on each side being placed above 16 others. The furnaces and stokers are of Babcock and Wilcox design and manufacture. The grates are horizontal, and are of the chain pattern; that is, each consists of an endless chain of transverse bars, which chain is slowly moved round front and rear pulleys, carrying the fuel slowly forward from the dead plate to the fire-bridge, where the ash and clinker is tipped and carried away by small steel waggons or skips. These run upon two lines of tramway (seen in Fig. 197) on the ground level, and are shifted by small electric (accumulator battery) locomotives. The boilers are upon the first and second floors above ground level. The depth of fire is not intended to exceed 3 or 4 inches, only the smallest steam coal being used. The chain-grate travels at an adjustable speed averaging about ½ foot per minute. The grate is 8 feet long, and has 83 square feet of surface.

The furnace of each boiler can be run right out in front from under the boiler for examination, cleansing, and repairs, the whole being mounted on a wheeled carriage, and the tram-rails on which this runs serving two opposite boilers facing each other.

Each grate is fed from its own hopper, receiving coal from the overhead bunker by a shoot hung on a pivot, so that it may be swung from side to side and thus distribute the coal well over the front part of the grate. The whole of the stoking machinery is electro-driven.

Babcock and Wilcox superheaters, consisting of clusters of ⊂

tubes set horizontally, are arranged over the steaming tubes, each boiler having 672 square feet of superheating surface. Green's economizers, in stacks of 10-feet-long vertical tubes, are placed immediately behind the boilers, each boiler being given 1540 square feet of economizer tube-surface.



TRANSVERSE SECTION THROUGH ENGINE AND BOILER ROOMS, CHELSEA GENERATING STATION.

FIG. 197.

The boilers are grouped in independent sets of eight, each set of eight supplying one turbine, and having a steaming power of 150,000 lbs. per hour.

32. The turbines are of practically the same design as those at Neasden, except that they are larger. Each end contains 21 crowns

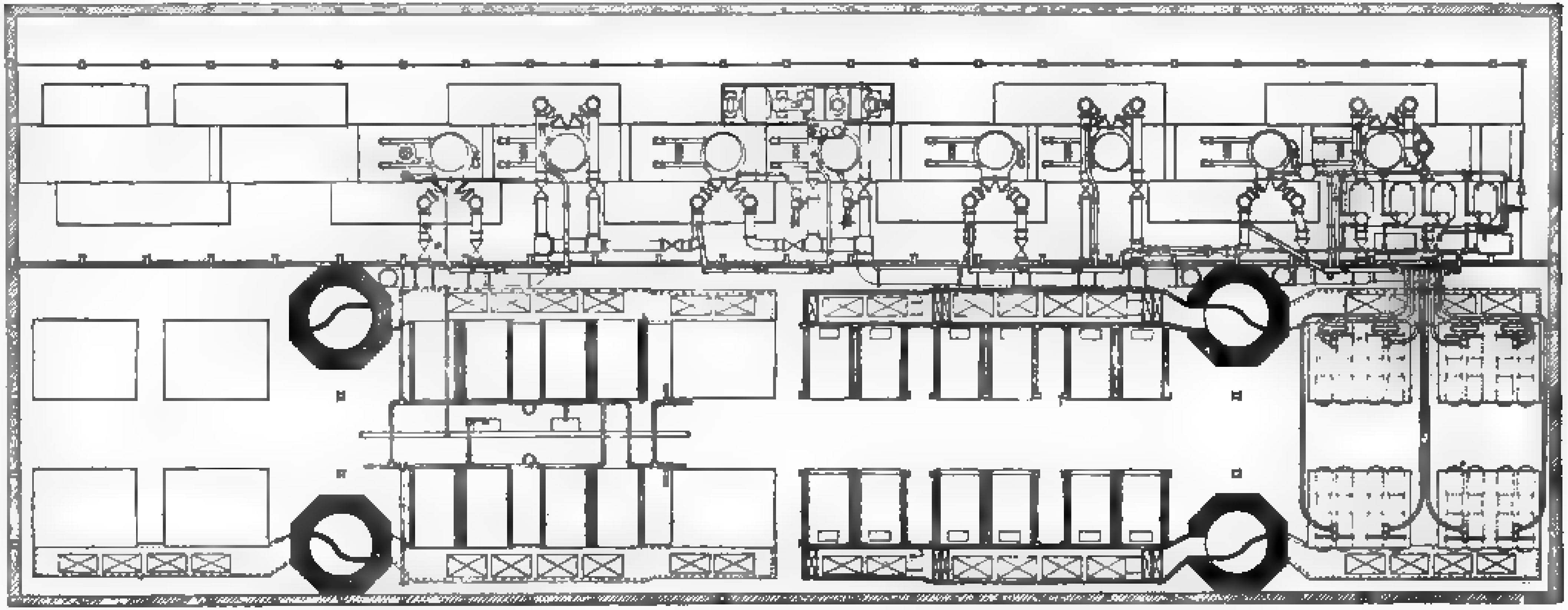


Fig. 198.—Plan of Chelsea Generating Station.

of rotating blades, with the same number of crowns of fixed guide-blades, including the "nozzles," or first ring. After the nozzles the blades are set in five groups, containing respectively 4, 7, 3, 3, and 3 crowns or rings, in which the radial lengths of the blades are respectively 1, 2½, 3½, 5, and 6½ inches, the blades facing the nozzles being also 1 inch long. The turbines are direct-coupled to the generators. They run at 1000 revolutions per minute, and the generators are 3-phase 4-pole machines giving 11,000 volts with a frequency of 33⅓ per second. The field rotates inside the external stationary armature, the whole being well furnished with ample ventilating ducts. The four exciter-engines are vertical compound steam-engines by Allen, of Bedford. The exciters are 125 kilowatts at 125 volts, and run at 375 revolutions per minute. Much of the auxiliary plant is motor-driven, and each unit has a complete independent auxiliary equipment.

As seen in Figs. 197 and 198, the turbo-generators are ranged in two lines with their rotating axes parallel to the length of the building, five in each line when the plant is completed, but at present only four in each line. From the plan it may be noticed that the machines are placed on the two lines zigzag fashion, each coming opposite the gap between two machines in the other line. This affords a clearer view of all the machines from the control gallery above, and also facilitates shorter and straighter pipe connections with the boilers. In the pit, down the centre of the engine-room between these two lines of turbo-generators, stand the vertical brass-tube surface condensers. Each condenser has 15,000 square feet of cooling surface, and the supply of circulating water comes from the Thames through a pipe 5½ feet in diameter. For each condenser there is a 20-inch centrifugal circulating pump. The air and the condensed water are drawn from each condenser by separate pumps. These and the circulating pumps are driven by induction motors, the current being 3-phase at 220 volts. In the top gallery there is a battery of nine 3-phase transformers, transforming from 11,000 volts to 220. These are air-cooled, and supply all the power for lighting and machine-driving in the central station, except the motors on the travelling cranes and the oil-switches which are driven by direct current at 125 volts from a small auxiliary steam-driven plant.

33. Along the north side and the east end of the machine-house stretch three galleries above the turbo-generator floor. On the first gallery are set the main generator high-tension oil-switches. These are of British Thomson-Houston manufacture, in which the switch is actuated by a small D.C. motor geared to the switch levers by high-ratio brass spur-tooth gearing. The motor takes about 20 ampères at 120 volts, or under 2½ kilowatts, to drive it, the driving continuing, however, only for less than 2 seconds.

The generators and these switches are grouped in pairs, each pair

delivering on to one bus-bar. Thus there are at present four such bus-bars (each triplex for the 3 phases), and there will be five later on. These are placed in five divisions of the second gallery. They are, or may be, connected by switches, so that any one bus-bar may be fed through its right or left hand neighbour when disconnected from its own pair of generators.

From each of these five bus-bars there rise to the third gallery

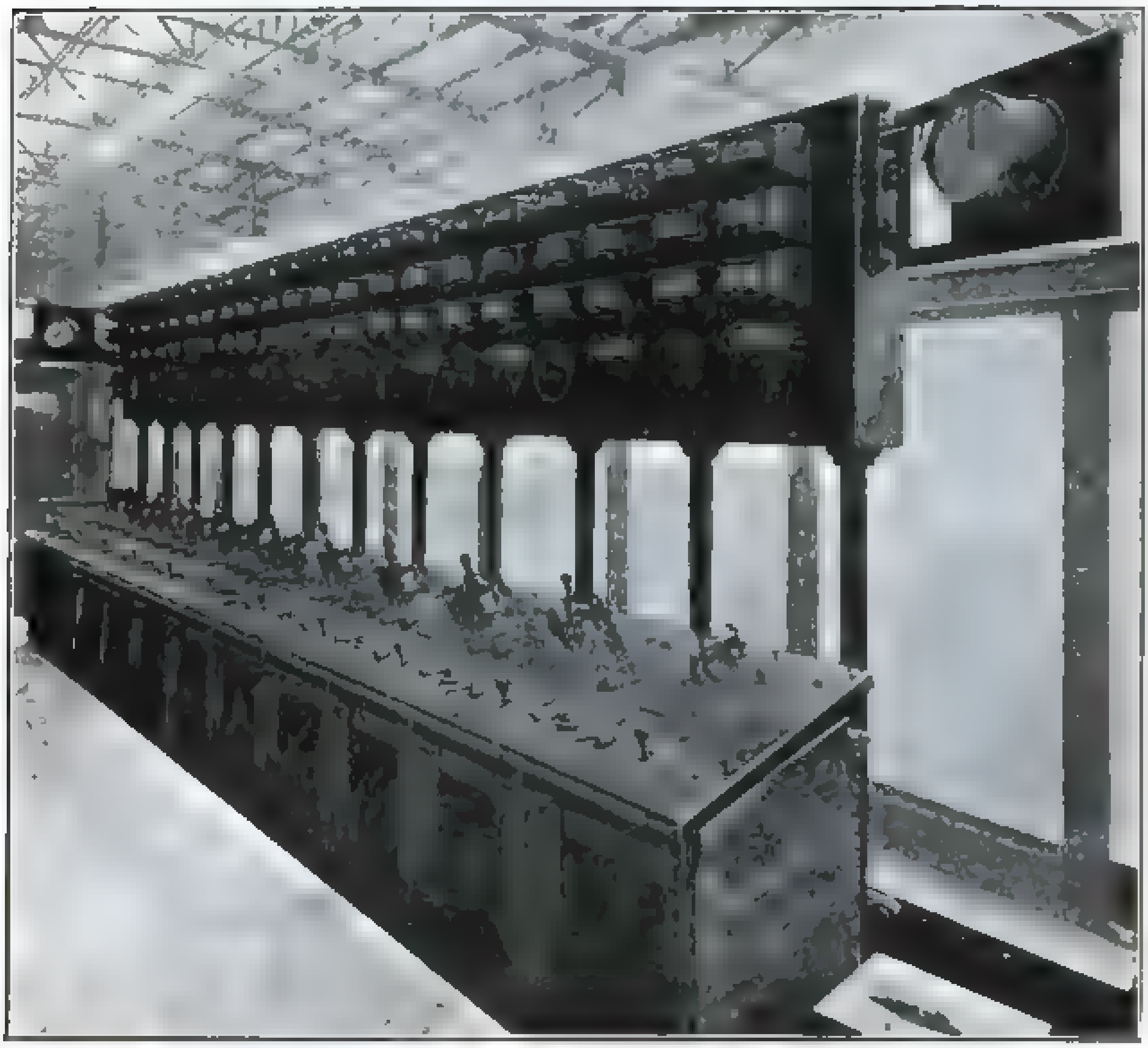


FIG. 199.—Chelsea Generator Control-board.

two main cables (each in 3 phases), and each such cable terminates in a 6-pole (triple 2-pole) oil-switch connecting it with a feeder bus-bar from which leads a group of feeders. There are thus at present eight, and will eventually be ten, groups of feeders. The switches between the feeders and the feeder bus-bars are also oil-switches of the same motor-driven British Thomson-Houston pattern, differing only in size from the generator and group switches.

There are, in all, 34 circuits at present provided for. Each is supplied in duplicate, so that there are 68 feeders, each 3-phase, so that the whole contain 204 leads.

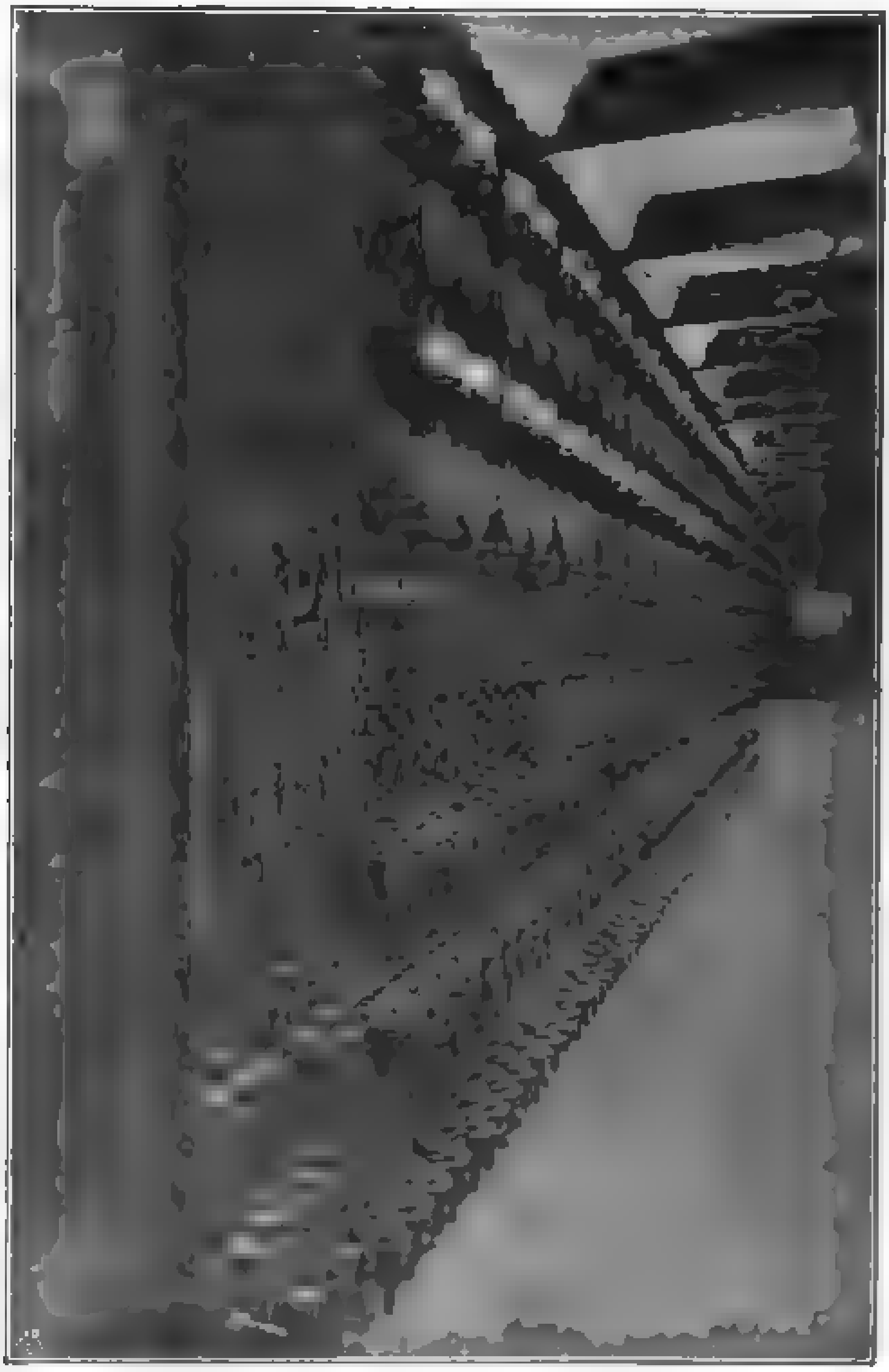


FIG. 200.—Chelsea Feeder Control-board.

The two duplicate feeders to any one section are taken from opposite ends of the switch gallery, and therefore from different generator bus-bars. Each section has therefore alternative channels of supply without the generator bus-bars being necessarily joined up.

34. The whole is operated from a low-tension master control-board placed in the centre of the second northern gallery. The generator desk is a horizontal table of eleven panels, for ten main generators and one auxiliary plant. This table stands on the edge of the gallery, facing outwards. The indicating instruments are mounted on vertical marble panels, whose lower edges are some 3 or 4 feet above the desk, thus leaving a clear view of the power-house under these edges. Each panel of the desk carries (1) a generator main-switch, (2) a field-switch, (3) field-rheostat ditto, (4) turbine-governor control ditto, and (5) a feeder-group bus-bar switch. The field-rheostats are situated on the end or eastern gallery of the second floor, and are all motor-driven. At present there are eight of them complete, while the motors and contact-circles for three others are installed without resistance-boxes attached.

Fig. 199 is a photographic view of this generator master control-board.

Behind this stands the feeder control-board, which is wholly vertical, and which is illustrated in Fig. 200. In this there are 17 panels, each controlling four feeder-switches, the duplicate feeders to one section being on different panels. Each panel carries the usual instruments and two signal-lamps to each switch; the lighting of the green lamp showing that the switch is open, and that of the red lamp signalling that it is closed.

From this gigantic central generating station energy is distributed at 11,000 volts between each pair of 3 phases to 27 sub-stations where it is reduced in potential by static transformers and converted to 550–600-volt direct current by rotary converters. Thence it is taken to the "third" and "fourth" insulated rails, as on the Metropolitan Railway.

35. In the year 1904 there was started into operation a complete system of surface electric railways along north Tyneside between Newcastle, North Shields, and Tynemouth at the mouth of the estuary, northwards along the coast to Whitley Bay, and inland as far as Ponteland, a total length of 37 route-miles, and 82 miles of single track. Here most of the electric equipment has been the work of the British Thomson-Houston Co. Direct current at 600 volts is used, and the return is by the running-rails. The two insulated rails for double track lie in the 6-foot way between the two lines, the distance between conductor and running-rail being 19 inches; and the current collecting-shoe is similar to that used on the Metropolitan, four collecting-shoes being carried by each motor-coach. A Vignole 80-lb. conductor-rail is used, with four round-wire copper bonds lying inside, and protected by, a pair of dished mild-steel fish-plates. The 90-lbs. bull-headed running-rails are similarly bonded. The soft-steel bond rivets are upset in the hole

through the rail-flange by a pressure of 20 tons from an hydraulic riveter, being shortened ¼ inch in the process, and thus ensuring close contact between the sides of the hole in the rail and the sweated-on copper end of the bond. The feeder terminals are connected to the conductor-rail by four ½-inch round copper bonds. The power is supplied to the sub-stations, of which there are five, at 5500 volts 3-phase, with the frequency 40 per second. This energy is bought by the railway company from the Newcastle Electric Supply Co., who have for this service laid down one 2000-kilowatt and two 3500-kilowatt Parsons turbo-generators, running at 1200 revolutions per minute. Steam at 200 lbs. per square inch and 150° Fahr.

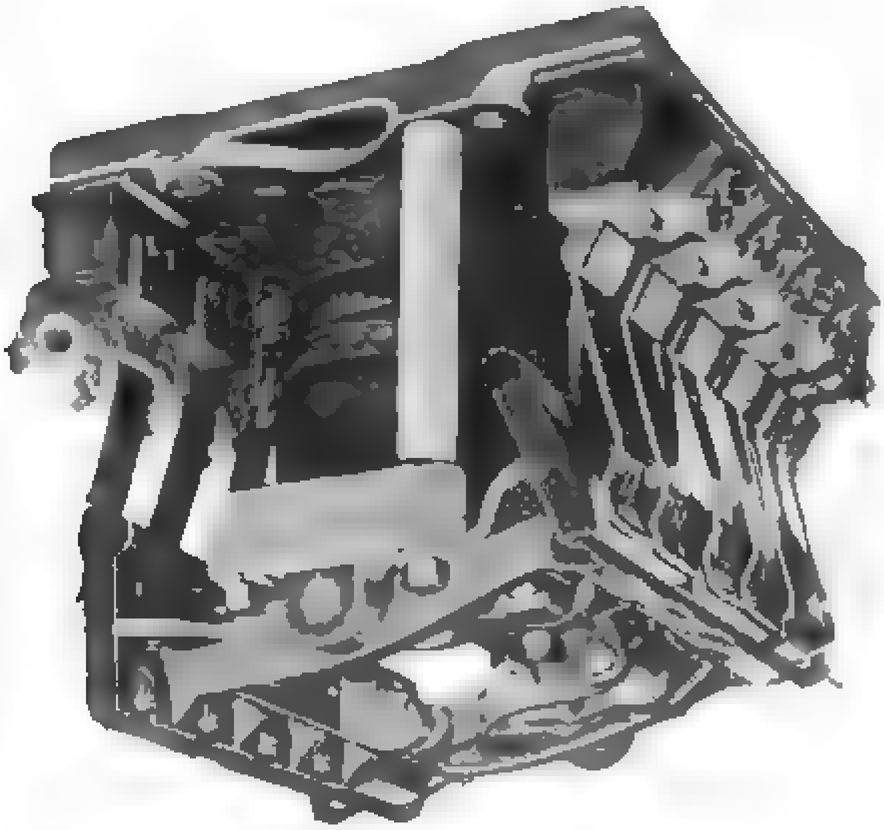


FIG. 201.—British Thomson-Houston Motor-coach Contactor.

superheat is supplied from Babcock and Wilcox water-tube boilers, the normal steaming capacity of the plant being 200,000 lbs. per hour. The high-tension switch gallery runs the whole length of the power-house, the oil-switches of British Thomson-Houston make being similar to those already mentioned as in use at the Chelsea central station. The whole is operated from a low-tension control-board, the various mountings on which perform the same functions as in those already described for the Neasden station.

The motor-coaches on the line have two bogie-trucks with 7-feet wheel-base, each carrying two 150 horse-power geared motors. The bolster of the truck is carried on three spiral springs at each end, and a spiral spring is interposed at the shackle at each end of the

plate-springs whereby the axle-boxes carry the truck-frame. The motor coach has a driver's cab at one end only, and from this, by means of a master-controller, the eight motors on one train are driven. The Sprague system used is the same as that described in the previous chapter for the Central London Railway. A nine-wire, or "nine-way," control cable runs the length of the train. The control current passing the master-controller is at about 550 volts tension, and averages $2\frac{1}{2}$ ampères for each motor-coach operated, all the switching being done by electric power unassisted by compressed air. The switches are termed "contactors," and are hung under the floor of the motor-coach, as are also the rheostat boxes. Fig. 201 is a good view of one of these British Thomson-Houston "contactors" uncovered to show its construction. There are thirteen contactors to each motor-coach.

On the Tyneside electric railways the average speed, including stops, is 22 miles per hour. Electric locomotives are being introduced for the goods traffic, but at present most of this work is still done by steam locomotives.

36. In 1904 there was also opened to the public an electric train service on the Lancashire and Yorkshire Co.'s line from Liverpool through Bootle to Southport, and, beyond this popular residential seaside resort, to Crossens. The route-length is about 22 miles, and on this there are 47 miles of electric single track. The line is one of very easy gradients, and only one curve of 7 chains radius occurs upon it. The $18\frac{1}{2}$ miles between Liverpool and Southport are run express in 25 minutes, and the local trains in 37 minutes, including stops. The generating station is at Formay, halfway between Liverpool and Southport, and there are sub-stations at Formay and at three other points. Three-phase current is sent out at 7500 volts, and transformed and converted to 650-volt direct current. A third-rail out-conductor and earth return by the track rails is the system used. The work has been done by Dick, Kerr and Co., as chief contractors, to the specifications of Mr. Aspinall, chief engineer of the Lancashire and Yorkshire Railway Co.

At one sub-station there are three rotary converters, and four at each of the three other stations. Each converter is an 8-pole machine giving 600 kilowatts at 375 revolutions per minute, and 25 per second frequency. The total converter capacity on the railway is thus 9000 kilowatts. The static transformers are each of 200 kilowatts capacity, three serving each converter, and are cooled by air blast. The fans are motor-driven.

At the generating station, Lancashire boilers, with 160 lbs. per square inch steam pressure, are used, along with Galloway superheaters and Green's economizers. The alternators are of the large-diameter low-rotary-speed Dick-Kerr type, with internal rotating

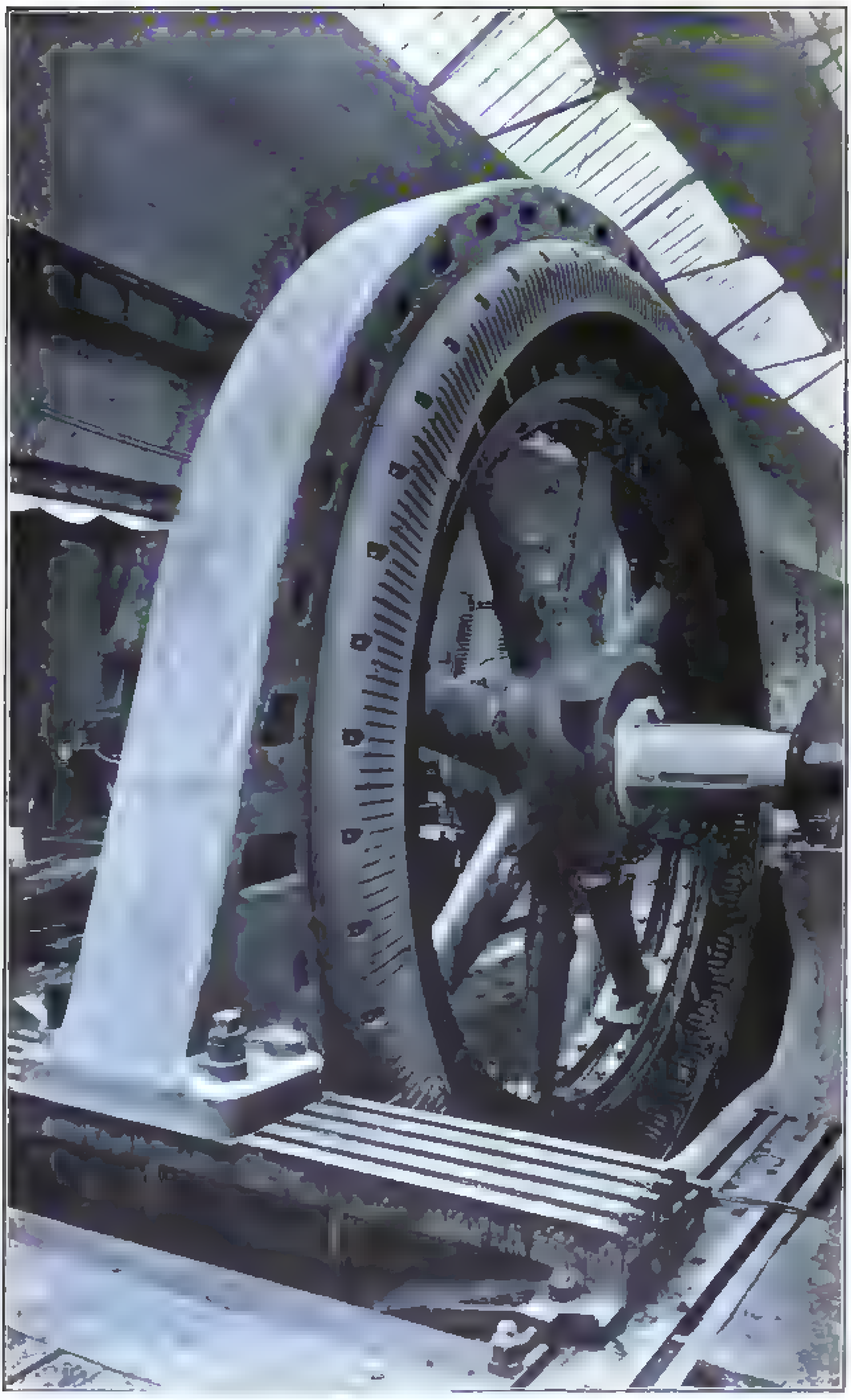


FIG. 202.—Dick-Kerr 3-phase 1500-kilowatt Alternator.

field carrying 40 poles, and external stationary armature, running at 75 revolutions per minute, and thus giving 25 frequency. The radial arms of the field are bolted direct to a 22-feet fly-wheel of 60 tons weight. Fig. 202 gives a photographic view of this alternator. There are four of these generators, each of 1500 kilowatt power, in the Formay station, and another similar machine of half this power, the total combined power of the station being thus 6750 kilowatts, or

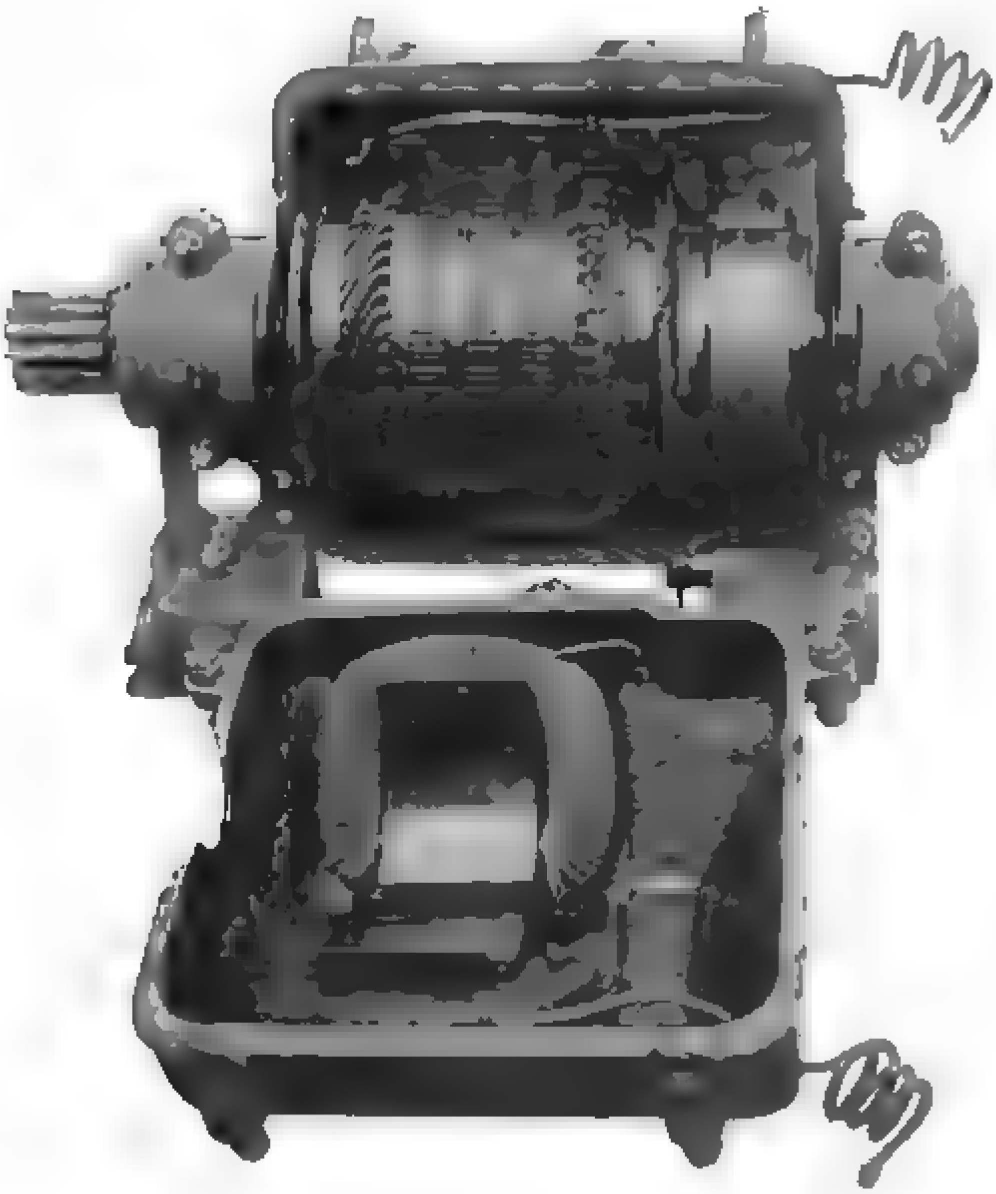


Fig. 203.—Bruce-Peebles Direct-current Traction Motor.

9000 horse-power, with about 25 per cent. steady overload capacity. The alternators are direct-coupled to horizontal cross-compound engines, with cylinders 32 and 64 inches in diameter by 54 inches stroke. At 160 lbs. steam pressure and 75 revolutions per minute, the normal power of each engine is 2300 horse-power, or about 12 per cent. greater than the normal electric output. These engines and the boilers are of Yates and Thom manufacture, and the small dynamo

is driven by a 1200 horse-power vertical compound engine (cylinders 23 + 46 inches by 42 inches stroke) by the same maker. The exciter dynamos are 4-pole 125-volt 100-kilowatt by Dick, Kerr and Co., driven by Willans and Robinson vertical compound engines. This installation is thus a public demonstration that an electric railway plant can be produced entirely by British manufacturing engineers, no foreign machines or material having found a place in

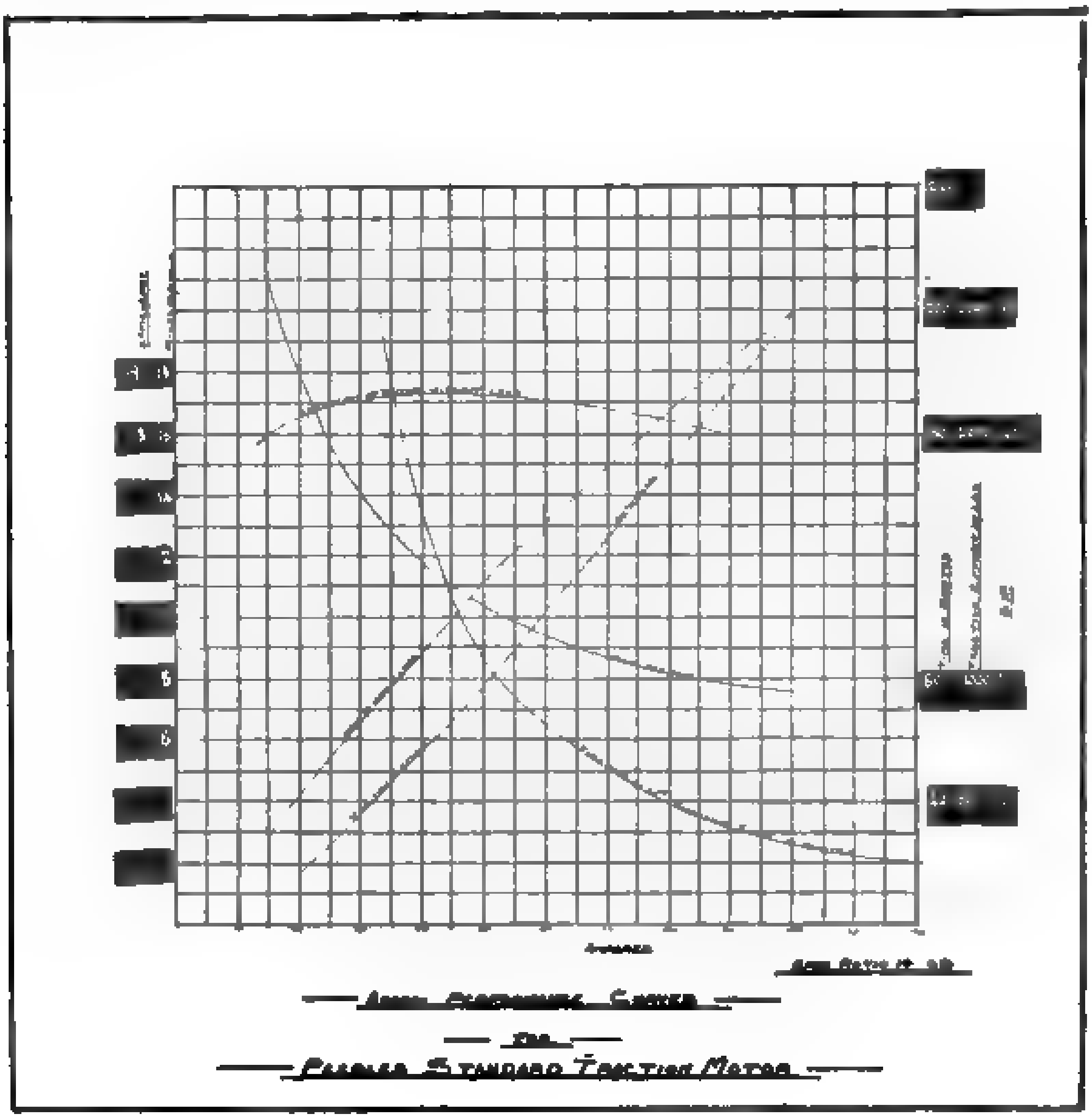


Fig. 204.

it. The high-tension switch galleries are all made fireproof, and distant control of the switches is employed. This control is not electrical, but is of mechanical construction, the switch-levers being moved by ropes stretched taut over pulleys.

Another Liverpool undertaking is the Mersey Tunnel Electric Railway. This had been operated by steam for many years, much to the discomfort of the passengers, and was electrified by the British

Westinghouse Co., the new service being started in May, 1903. The line is a short one, under 4 miles in route-length, but of 12¼ miles single track, with very heavy traffic, the load curve of which has daily two severe peaks. The third and fourth insulated-rail system followed is generally the same as that described for the Metropolitan, except that an electro-pneumatic "drum," or rotating, controller is used on the cars instead of a "turret" controller. The fourth rail is earthed at the power house, which contains three 1200-kilowatt and two 200-kilowatt compound-wound direct-current generators, 650 volts, supported through the peaks by a battery of 320 chloride cells of 1000 ampère-hour capacity. The main engines are condensing vertical cross-compound with high-pressure drop valves and low-pressure Corliss valves, working at 160 lbs. per square inch steam pressure, with 100° Fahr. superheat and 27 inches vacuum. The train service is a 3-minute one, the trains varying in size from three to six coaches. Each motor-coach carries four 100-horse-power 600-volt motors. A mean speed of 20 miles per hour is maintained. A three-coach train consumes 9 kilowatt-hours of energy per train-mile.

37. Indeed, all electric tramway and railway material can now be supplied from English and Scotch workshops, of the highest quality both in design and workmanship. Several of the manufacturers have already been mentioned, and, among others, Messrs. Parker and Co. of Wolverhampton, Messrs. Mavor and Coulson of Glasgow, the Electrical Construction Co., and Messrs. Bruce, Peebles and Co. of Edinburgh, deserve notice. The last-named firm will appear again in a later chapter in connection with high-tension 3-phase railways. Meantime, on account of the special excellence of its workmanship, we illustrate here the 35 horse-power continuous-current traction motor of this firm in Fig. 203. It is a 4-pole machine designed for 500 to 600 volts, and with gear-ratio 1 to 4·86. Fig. 204 gives its various characteristic curves set out on the usual base of ampères output up to 100 ampères. The tractive effort and speed curves are calculated for 30-inch driving-wheels. The brake horse-power ranges from 50 at 7½ miles per hour, through 35 at 9 miles, to 7½ horse-power at 20 miles per hour. The motor efficiency is 0·81 at 8 miles, 0·86 from 10 to 13 miles, and falls again to 0·81 at 20 miles per hour.

CHAPTER IX

BERLIN ELECTRIC RAILWAYS

1. THE earliest serious work in electric main railways was done in Berlin, under the auspices of Messrs. Siemens and Halske.

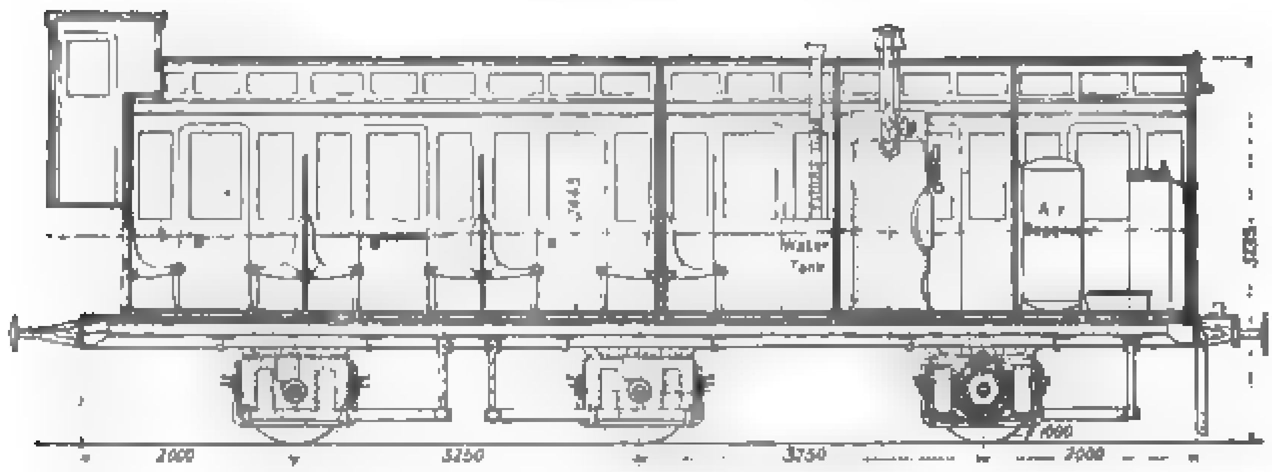
Outside Berlin is an extremely beautiful district made specially picturesque by a number of wooded lakes, one of which is called the Wannsee. This has become a favourite residential quarter for the well-to-do, and the most popular holiday-field for the rest of the people of Berlin. Messrs. Siemens and Halske proposed the electrification of the railway from the Potsdamer Bahnhof which serves this district, and, after a year's preliminary trials, obtained permission from the Prussian State Railway Department to commence a regular public service in August, 1900. The State control of railway matters is more arbitrary in Germany than it is here, and during a trial of two years, from 1900 to 1902, the conditions imposed were such as to preclude the possibility of demonstrating the commercial and financial advantages of electric traction. Only one electric train was allowed to run, interposed between numerous steam trains. The steam service was thus maintained almost intact along with all the arrangements adapted to a steam service. The whole of the electric equipment of the line and of the electric supply plant were thus devoted to work which was a mere fraction of their capacity, while the size, the speed, and the frequency of the trains were maintained unaltered and wholly unsuited to encourage that development of traffic which is one of the most important economic

features of electric traction. Under these conditions also two large accumulator batteries were required as part of the plant. These would not be used if the whole service were electric.

The two years' running was, however, a demonstration of the efficacy of electric power to deal with heavy suburban railway traffic.

2. The running was throughout very successful, practically without incident of any kind; and absence of vibration and shock throughout the train has been noticeable, in spite of the fact that the train is driven partly by pull from the head and partly by push from behind. The change over from series to parallel coupling of

Fig. 205.—Elevation.



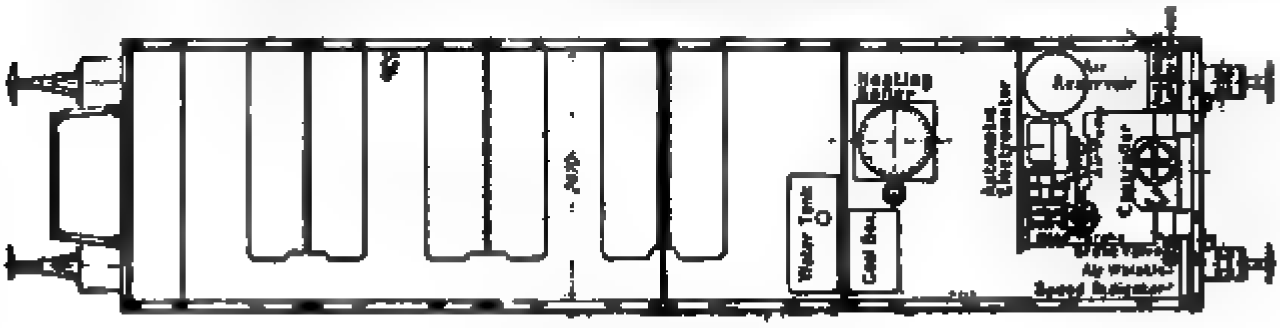


Fig. 206.—Plan.
Motor-coach on Wannsee Railway.

the two motor groups is accomplished perfectly smoothly. No wear or accident has occurred with the supply rail. The bonding of the running-rails was at first made with 8 millimetre copper wire, and these frequently broke, so that stranded copper cable has been substituted. The block-system signals and telephones were at first arranged with earth returns, but the working current returning by the running-rails was found to disturb the signals, and insulated metallic returns for the signal system have been therefore added. Before the stranded bonding of the rails was complete, the measured resistance of the earth return was 0·045 ohm per kilometre, or 0·072 ohm per mile; but with the more perfect bonding completed

it was reduced to about 0·04 ohm per kilometre. In dry weather the insulation was found to be 3,700,000 ohms on one kilometre length, and this falls to 55,000 ohms in wet or misty weather.

The current is supplied from the Gross-Lichterfelde works of Siemens and Halske, and is continuous current generated at 750 volts. At full-speed the train of ten carriages, weighing, empty, 193 tons, absorbs approximately 250 horse-power. The loaded train weighs 220 tons, and the average energy consumption, measured on the train, is 6½ kilowatt hours per train-kilometre, which corresponds to 47 watt-hours per ton-mile.

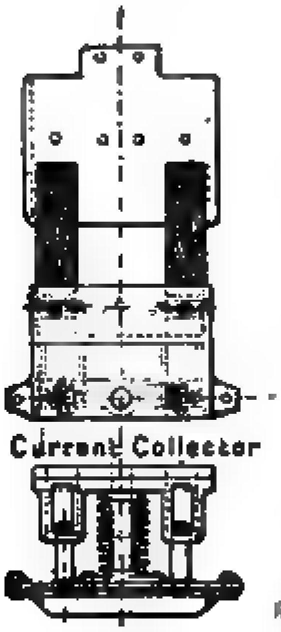


Fig. 208.—Collector-shoe.

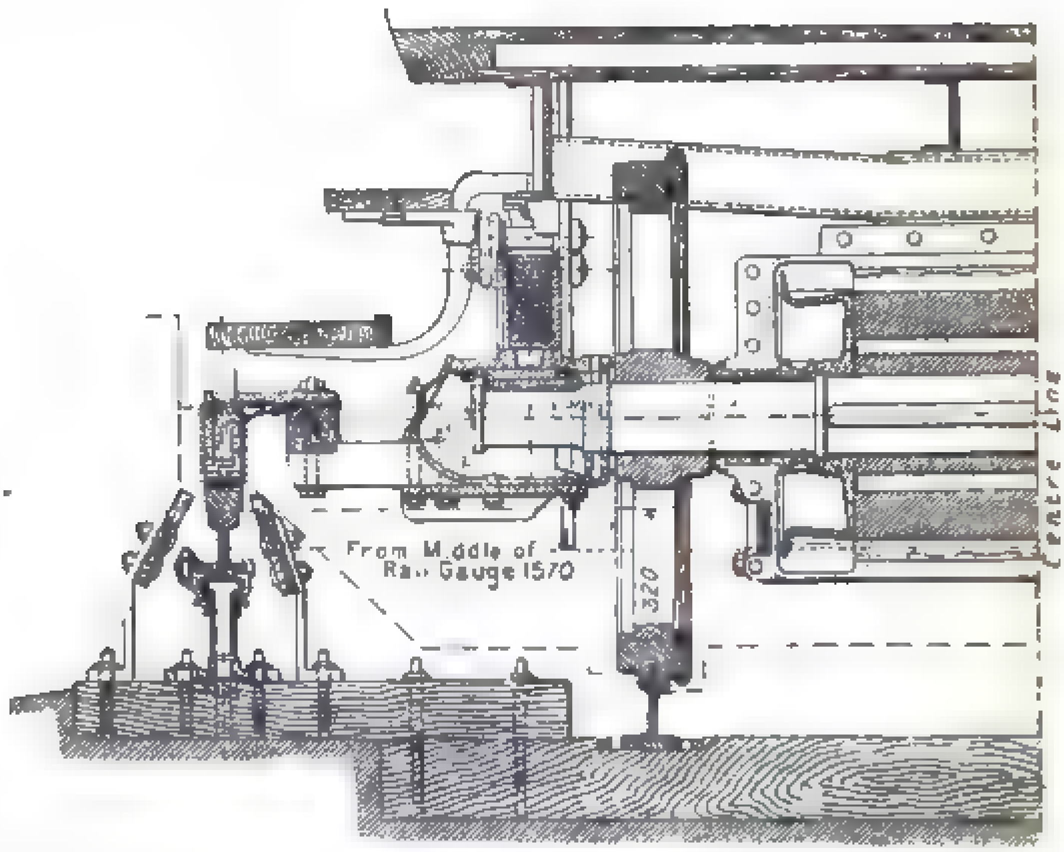


Fig. 207.—Section of Motor-axle and Third Rail.

3. There are four intermediate stations between the Potsdamer Bahnhof and the terminus Zehlendorf, namely, Grossgörschen, Friedenau, Steglitz, and Lichterfelde. The total length is 18½ kilometres double track, plus 3 kilometres sidings, or 40 kilometres single track. The centre of gravity of the traffic is at Steglitz, 6·8 kilometres from Berlin, and the shortest distance between stations is from Berlin to Grossgörschen, namely, 1·9 kilometre, for which the time-table (adapted for steam traction) allows 3½ minutes. The maximum speed is 50 kilometres, or 31½ miles per hour, and the average, inclusive of stoppages, 31 kilometres, or 19½ miles per hour.

The train is made up of five 3-axled third-class, one 2-axled third-class, and four 3-axled second-class coaches, all of standard dimensions.

The leading and trailing coaches are converted to motor-cars, and each carries three motors, one on each axle. There are no bogie-trucks, and the motors act direct on the axles without gearing.

4. Figs. 205 and 206 show the arrangement of one of these motor-cars. The six motors driving the train can be driven from the cab at either end. Westinghouse air-brakes are mounted on each of the ten coaches, and the air-pump for these is driven by an electro-motor, the current to which is automatically switched in and out when the air pressure reaches the lower and higher limits $6\frac{1}{2}$ and 8 atmospheres. The train is electrically lighted, but warmed by hot water, for which purpose a small boiler, a coal-box, and a water-tank are carried in the motor-car.

5. The generating station not being close to the line, the current is brought down to the line by overhead wires upon wooden poles. It is taken along the line by a third rail at one side of the track elevated

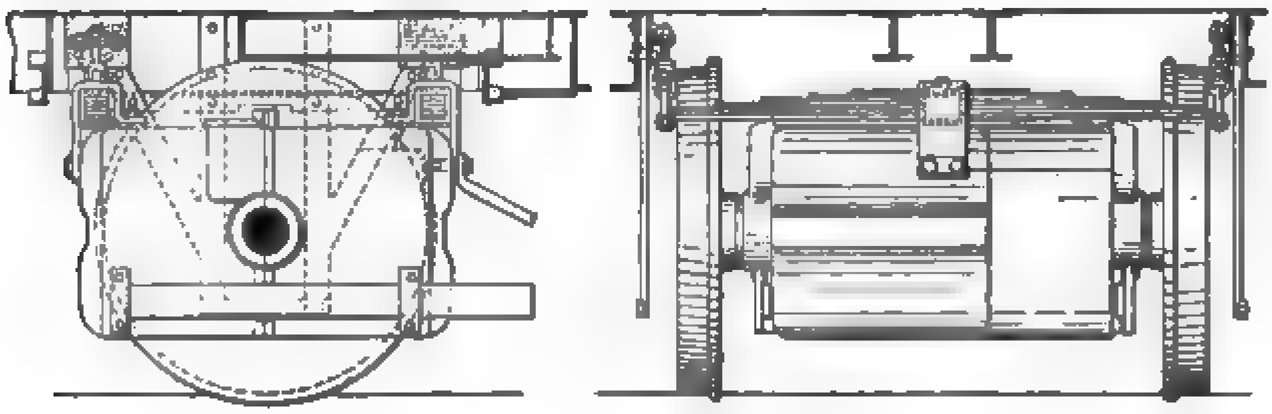


FIG. 209.—Motor Spring Suspension.

about 13 inches above track-rail level, and protected by two stout wooden plank-guards, as seen in Fig. 207.

The current is collected from this rail by six sliding-shoes, which are suspended from the axle-boxes of the six axles of the leading and trailing cars. The return is by the running-rails, which are copper-bonded and earthed. At double crossings there is a break 50 feet long in the collecting-rail, but since there are collecting-shoes at each end of the train, which has 350 feet length, this break creates no difficulty.

The mounting of the collecting-shoes on the axle-boxes and that of the collecting-rails on their insulators are clearly shown in Figs. 207 and 208. The rubbing surfaces are flat, the shoes having no flanges. The insulator standards are screwed to short timber sleepers, which are again screwed to the sleepers for the main running-rails. The collecting-rail and the near running-rail are thus kept rigidly in true relative position. The insulator pillar is of iron, covered with hard rubber, on the top of which is clamped a two-part cast-iron cap

which grips the collecting-rail. The insulators are spaced at from 13 to 17 feet apart. The plank-guards are bolted to flat-iron brackets bolted to the sleepers. The bearing-surface of each collecting-shoe is 12 inches long by 2 inches wide. The shoe is suspended by two slack links from a wood and iron bracket fastened to the under side

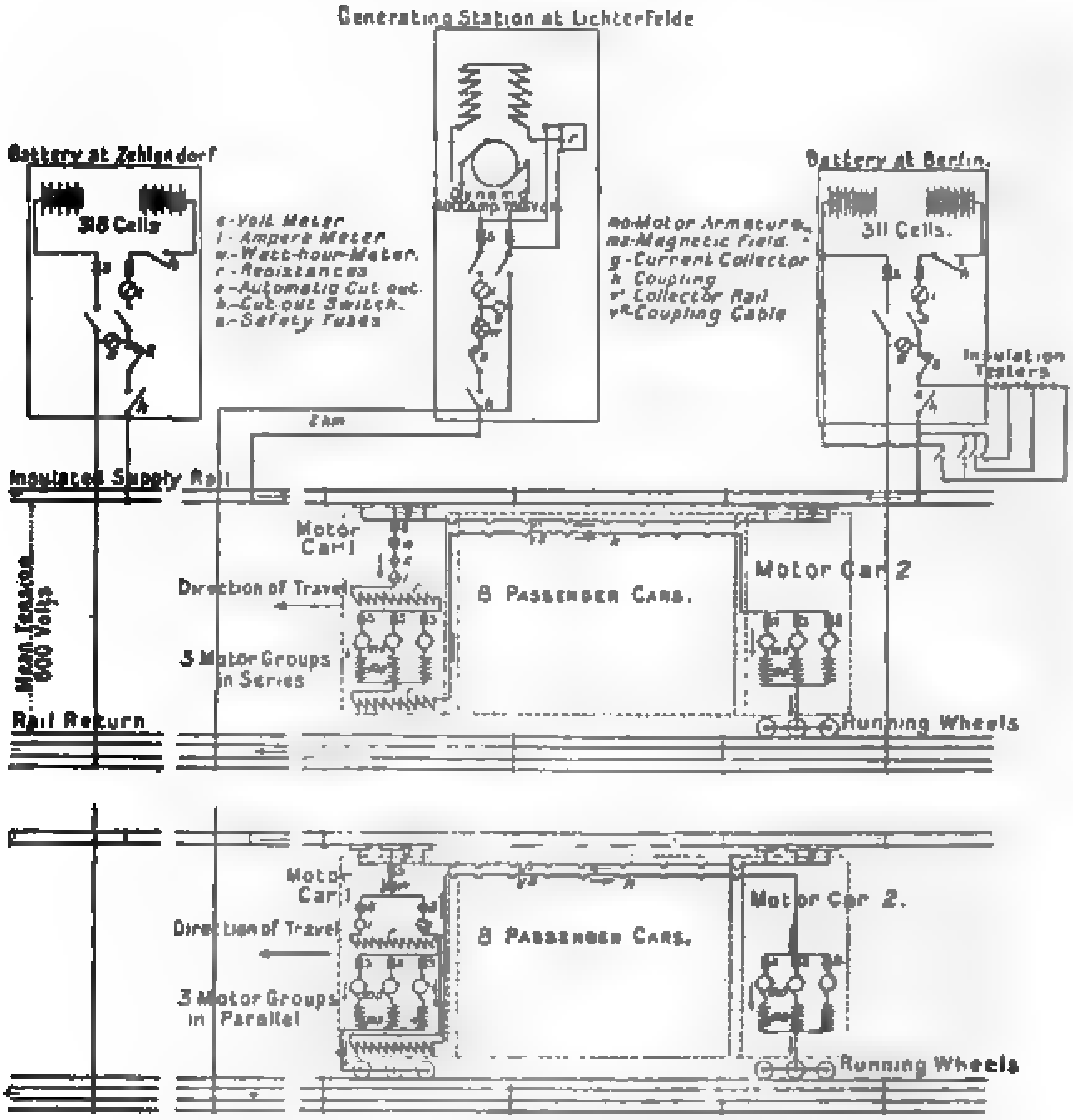


FIG. 210.—Diagram of Motor Connections and Control.

of the axle-box. At the mid length of the shoe is fastened to its upper side a stout cylindric plunger, sliding vertically in a hollow guide fashioned on the under side of the bracket, and round this guide is placed a strong spiral spring pressing the shoe against the collecting-rail. It will be noted that this suspension of the shoe keeps it steadily at rail-level so long as the tire is in contact with

the running-rail; it imparts to no portion of the suspended mechanism any of the vertical swing or oscillation of the underframe of the carriage. It also avoids all difficulty in rounding curves, these producing no side displacement of the shoe, so that this does not need to be made wider than the rail.

6. The weight of the motor-car is 33 tons. Since there are two to each train, and all the axles are driving-axles, the adhesive weight is 66 tons. The motor drives direct on the axle, the armature being keyed to the axle, and the two-part magnet field rests partly on bearing-sleeves on the axle and partly on the underframe, being hung from this by a vertical link and a horizontal beam. In Fig. 201 no springs are shown in this suspension of the field from the underframe; but a spring suspension is being used on other motor-cars of later design. This suspension is shown in Fig. 209. The spring tension is adjusted so as to almost entirely relieve the driving-axle of the weight of the magnets. The weight of the magnets is over 2½ tons, while that of the wheels, axle, and armature is under 2 tons.

The front of the driver's compartment is fully glazed, and the driver, standing behind the controller, has an uninterrupted view of the track in front. The valve of the air-brakes and an air-whistle are within reach without his moving from his place. Each driving-box contains also an air-pump, a hand-brake, safety fuses and cut-outs, watt-hour metre, ampère and volt metres, and a speed indicator; a switch-board commanding these instruments and machines, as also the signal apparatus.

The starting resistances are of rolled sheet, and are placed partly in the roof and partly in the floor of the car. The resistances of the car which for the time being heads the train are alone used. Fig. 210 shows the scheme of the method of control. In starting, the three motors of the leading car are worked in parallel, and the three on the trailing-car are also in parallel; but the two groups are placed in series, and the two resistances of the leading group come also in series. This grouping is shown in the upper part of the figure. After 16 kilometres per hour speed is reached the grouping in the lower part of the figure is used, where the current splits before entering the resistances, the two resistances being thus inserted in parallel and all the six motors being worked in parallel. During the commencement of each period the resistances are taken out gradually step by step. With careful handling the method makes it possible to maintain a practically uniform tractive effort during the whole period of acceleration.

Each controller consists of two spindles, one of which regulates speed in the manner just described, while the other operates switches giving the following six arrangements: (1) Forwards with motor-car, I. and II.; (2) forwards with motor-car, I. alone; (3) forwards with

motor-car, II. alone; (4) brakes on motor-car, I. alone; (5) backwards with motor-car, I. alone; (6) cut-out. Here I. means the leading and II. the trailing motor-car. In normal running position I. is alone used. In each of the positions 1 to 5 the speed regulator is graded in fourteen steps.

7. In the generating station at Lichterfelde the current is obtained from a Siemens and Halske outside armature dynamo giving 400 ampères at 750 volts, which, however, is run at 900 volts when the batteries are being charged. This is driven by a 500-horse-power condensing engine of Borsig construction. Heine boilers of 200 square metres heating surface supply the steam. In the batteries at

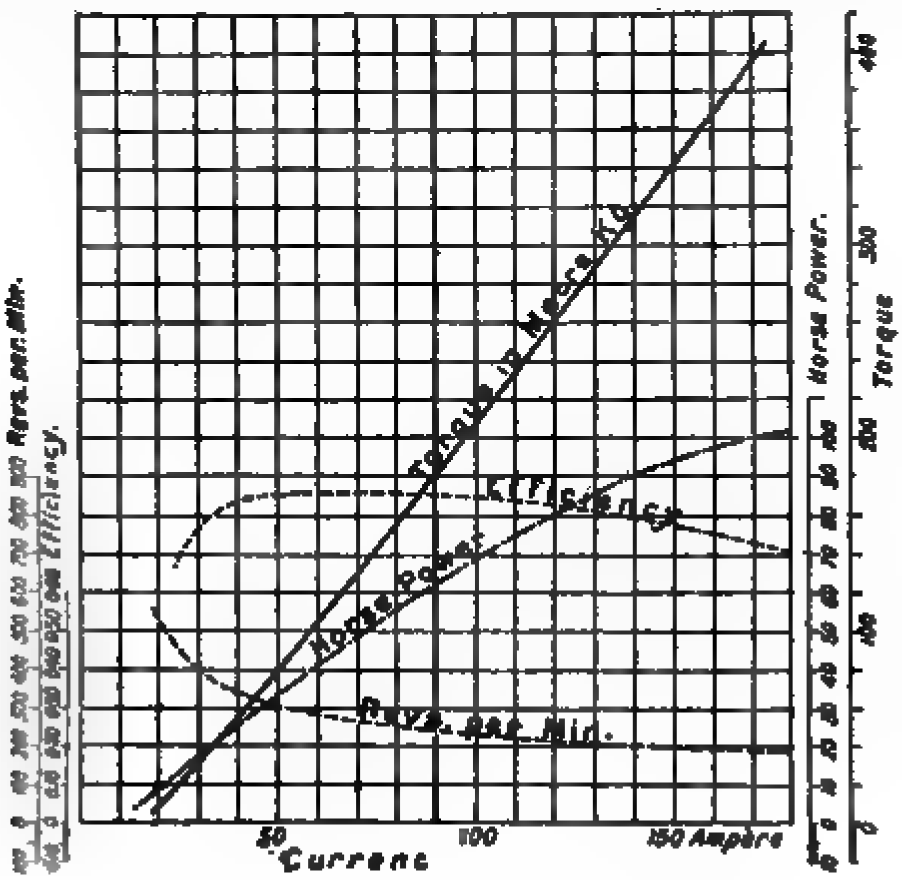


Fig. 211.—Performance Curves of Motor.

Berlin and Zehlendorf there are 311 and 318 cells respectively. They are capable of giving a maximum current of 500 ampères, and have a capacity of 814 ampère-hours in a one-hour's discharge, or 1138 if discharged over three hours.

8. Fig. 211 gives characteristic curves of one of the car motors obtained from brake tests. The horizontal ordinates in the diagram are ampères of current, while the heights of the various curves give the simultaneous (1) speed in revolutions per minute; (2) torque in metre-kilograms; (3) performance in horse-power; and (4) efficiency. The armature resistance is 0·18 ohm, and that of the magnet windings 0·31 ohm, while the voltage for the test was 600. The current

through each motor is not allowed to rise above 200. The diagram (Fig. 211) runs up to 180 ampères. Up to 140 ampères the efficiency is above 80 per cent., being 85 per cent. from 50 to 100 ampères. It falls to 70 per cent. at 180 ampères, when the horse-power is 102,

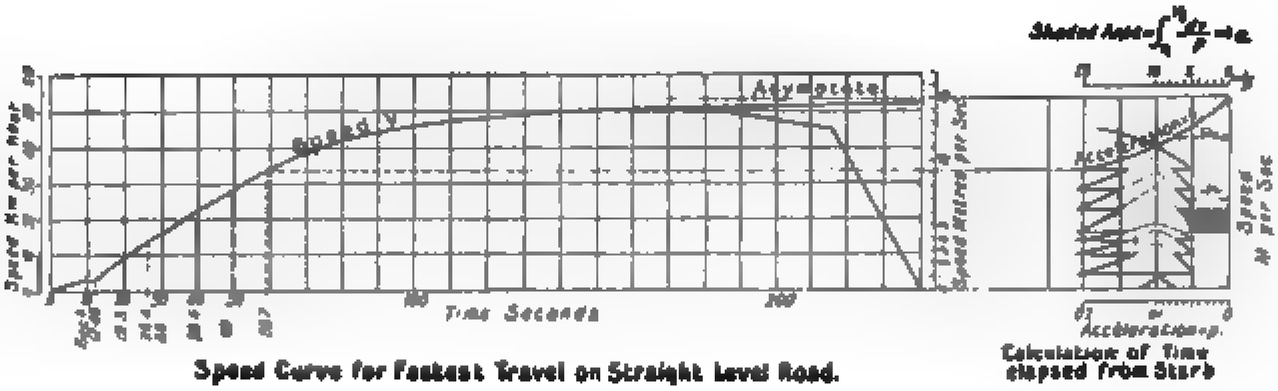


FIG. 212.—Acceleration and Speed Diagrams.

and the driving moment 420 metre-kilograms. From this diagram, which gives a co-ordination between each speed and the tractive effort supplied by each motor, there is obtained, by help of a diagram which

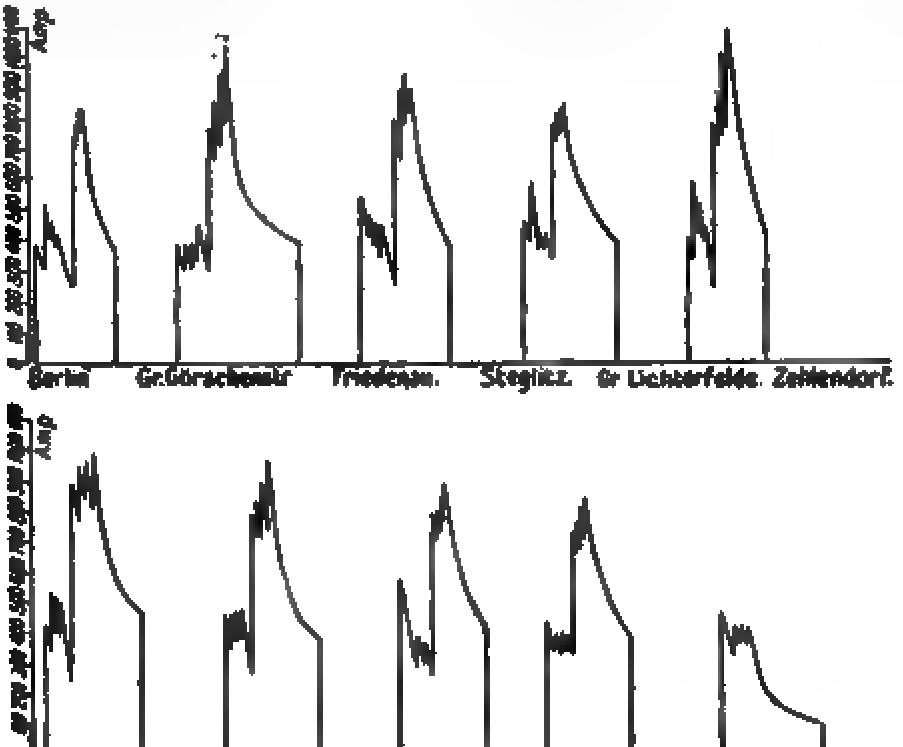


FIG. 213.—Current Consumption on Cars.

we do not reproduce, diagram Fig. 212. The left-hand portion of this co-ordinates the time in seconds, from the beginning of the run of the 220-ton train on a level straight road, and its speed, the latter measured vertically. This left-hand portion is calculated from the

right-hand portion, in which are co-ordinated the speed—vertical—and the balance of tractive effort above the rail- and axle-resistance giving acceleration, this latter being converted into terms of acceleration in metres per second per second. The 16 kilometres per hour, at which speed the throw over from series to parallel working occurs, is reached in 30 seconds. The other breaks in the curve correspond to the taking out of successive resistances. The maximum velocity attainable according to diagram is 53·7 kilometres, or 33½ miles per hour; and the average acceleration up to the moment at which the last resistance is taken out is 0·16 metres per second per second, or less than $\frac{1}{16}$th that due to gravity.

Fig. 213 gives the actual current consumption on the out and return journey as measured in the motor-car itself, readings being taken every five seconds during an ordinary run with average load of passengers.

In Fig. 214 the height of the upper curve gives the voltage in the supply main as measured at Zehlendorf, while that of the lower line gives the ampères of current supplied from the battery there. It will be noted that a very small falling off in voltage brings the battery into vigorous action. In Fig. 215 is recorded the simultaneous current output from the generating works, and if Fig. 215 be examined in connection with Fig. 214 the correspondence between the two is easily seen and is very instructive.

A complete set of measurements were taken on the car itself between Lichterfelde and Zehlendorf on a half-filled train, weighing about 200 tons. The chief results of this test are here given:—

	Maximum.	Mean.
Voltage	700	600
Current ampères	1100	600
Horse-power absorbed	830	470
„ utilized	690	330
Efficiency	·85	·70
Tractive effort, kilograms	6000	3200
Acceleration, metre per second-second	0·24	0·11
Speed, kilometres per hour	50	36

The maximum momentary current recorded has been 1200 ampères on a 200-ton train, or 5½ ampères per ton. If all the traffic on the line were electric driven—there being 107 ten-coach trains in each direction daily—and especially if the number of trains were doubled and the weight of each halved with five coaches only per train, this starting current for an individual train would put no strain upon the central station plant. But with the impracticable restriction to one very heavy electric train, the load-factor is brought

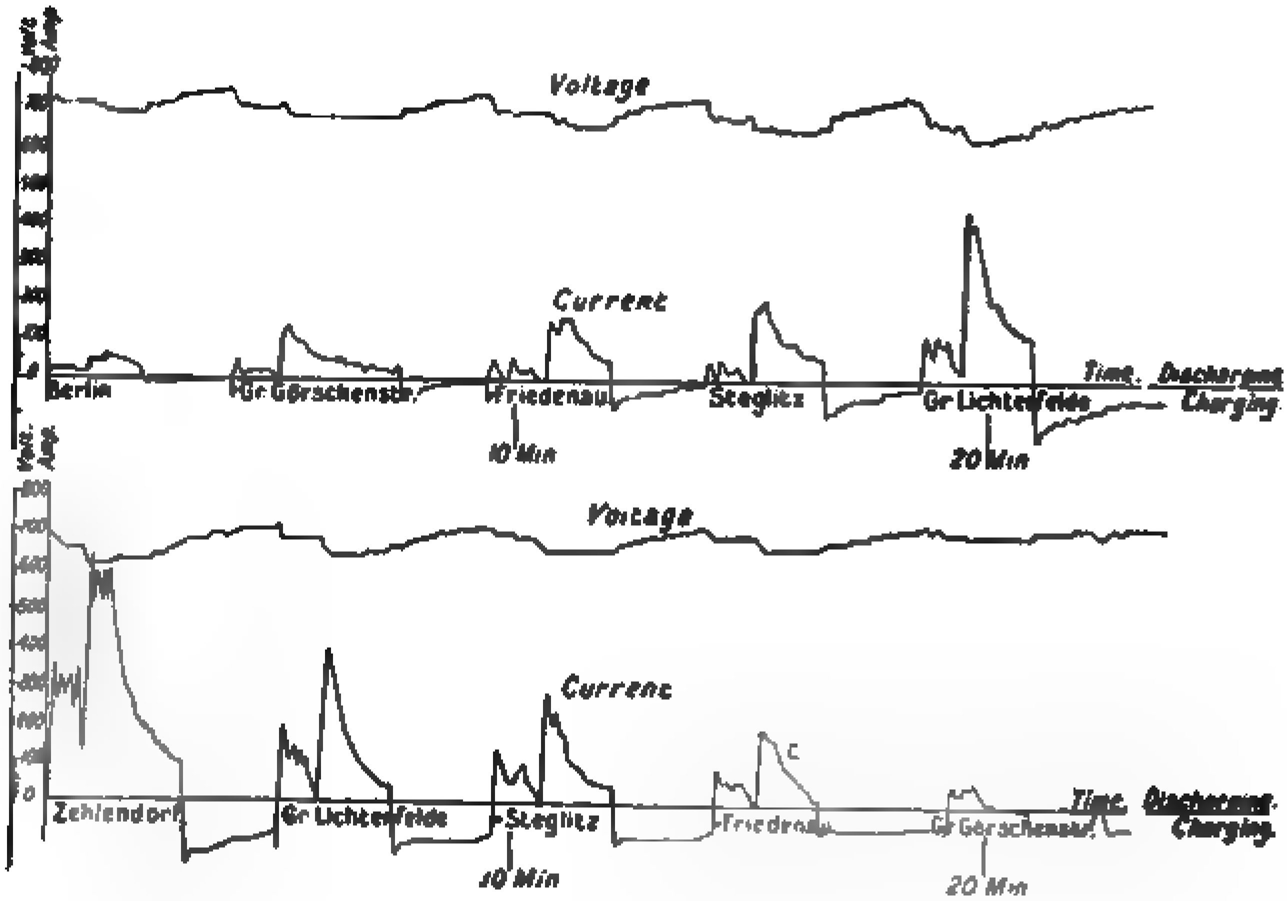


FIG. 214.

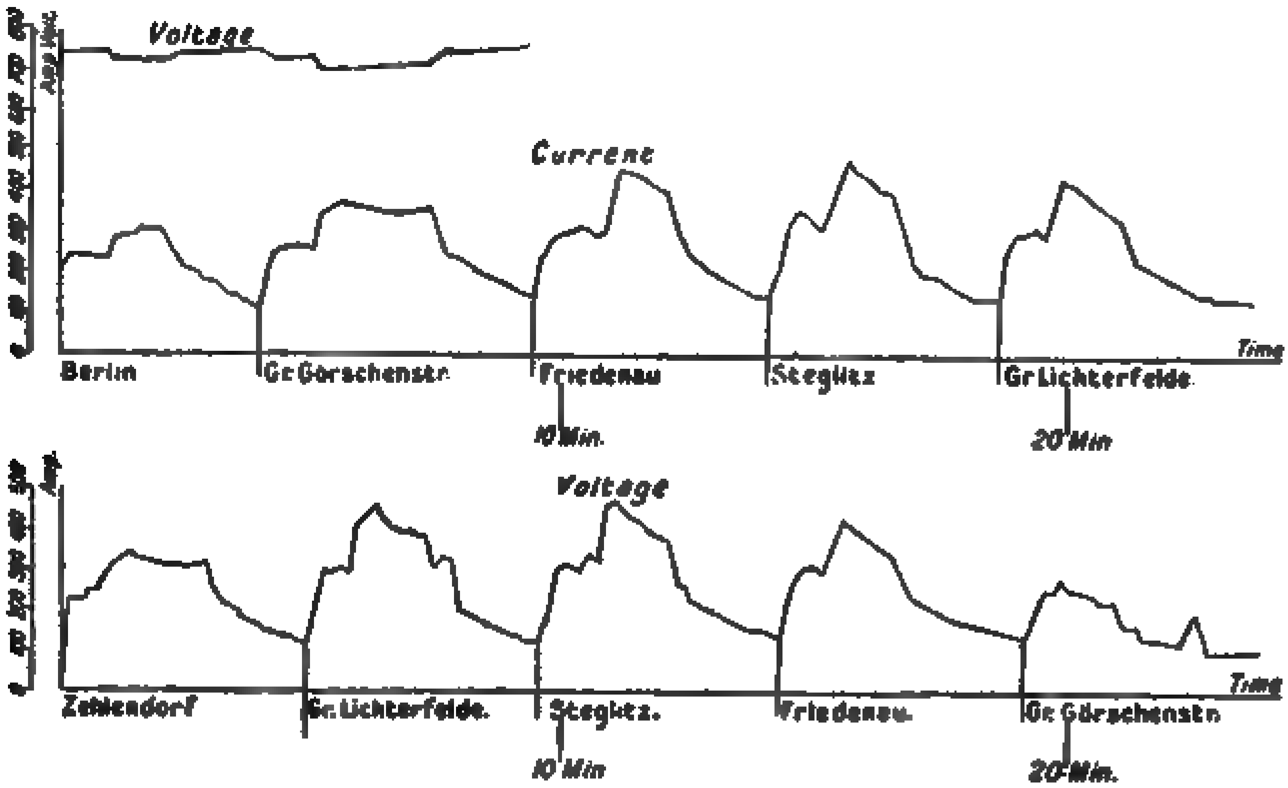


FIG. 215.

down absurdly low, and what lighting engineers call the "diversity factor" is at its minimum. Thus the central station must either be seriously strained or must involve a capital outlay out of rational proportion to the work to be done. This disadvantage is only mitigated in a small degree by the erection of the two large storage batteries at the two termini.

9. Estimates for the complete electrification of the line have been made by Ingenieur R. Rinkel. These are interesting to British engineers who desire to compare the costs of work in England and in Prussia. The total running costs of the steam locomotion on the line are found to be 23 pfennig, or $2\frac{3}{4}$ pennies, per train-mile. Reckoning 32 watt-hours per ton-kilometre (= 51 per ton-mile), and estimating on the basis of the present (1903) traffic only, with also the present time service and train weight, the cost of electric traction would be 32 pfennig. But reforming the whole system to make it suit electric power and develop the traffic proper to electric traction, but leaving one-third of the bright-weather, summer-holiday peak of the traffic-load to be dealt with by steam locomotives; adhering also to direct-current generation and transmission, and adopting electric locomotives in preference to motor-coaches, designed for five-coach trains with mean speed of 50 kilometres per hour and acceleration 0·35 metres per second-second, each with four motors of 75 rated horse-power, the following figures are arrived at:—

Capital Cost for 40 Kilometres Single Track with Direct-current Generation at 800 volts.

	Marks.
Central station at Steglitz	1,300,000
Batteries, 3400 kilowatts	421,000
Transmission	800,000
24 locomotives of 300 horse-power, each 45,000 marks	1,080,000
Repairing workshop	50,000
Sundries	49,000
Total ...	3,700,000
Extra to provide for Summer-holiday Peak.	
Transmission	250,000
10 extra locomotives	450,000
Total ...	4,400,000
	= £220,000.

or £8800 per mile single track.

With three-phase generation at 6000 volts at the central station, the capital cost worked out at 3,230,000 marks, in place of 3,700,000 with direct current.

The yearly working costs were estimated to be—

	Marks.	Per cent.
Traffic expenses	166,000	19·4
Power	325,000	38·0
Maintenance and repair	106,000	12·4
7 per cent. interest and depreciation on capital	259,000	30·2
Total ...	856,000	100

For the same service worked by steam locomotives on the basis of the present working costs, the yearly expenditure was estimated to be 915,000 marks.

10. In July, 1903, the "Union Elektrizitäts Gesellshaft," which is the German Thomson-Houston Co., commenced electric running on a short line of 9·2 kilometre route-length, stretching from the Potsdamer Bahnhof in nearly the same direction as the Wannsee. The smallest curve on the line is 300 metre radius, and the steepest gradient 1 in 150. The distance between stations ranges from 3115 to 1141 metres, and averages 1800 metres. Seventeen minutes are taken for the 9·2 kilometres run, excluding stoppages; or 32½ kilometres = 20 miles per hour.

Direct current at 550 volts is transmitted by an insulated third rail, and the return is by the track rails. The third rail stands 310 millimetres higher than the track rail, and on the outside at 320 millimetres distance. These rails are 41 kilograms per metre length, and are laid in 15-metre lengths.

Each train consists of three motor-coaches, and weighs 124 tons. These are placed on bogie-trucks, each truck carrying two motors. The truck frame is carried by plate-springs, with a volute spring in each suspension shackle; and the bolster is carried by a pair of double-elliptical transverse plate-springs. The wheel-base of the truck is 2½ metres, and the two trucks are distant, between swivel-pins, 13·2 metres. The motors are geared in the ratio of 1 to 4·22, and each has a one-hour overload capacity of 125 horse-power, the normal power being 125 ampères by 500 volts, or about 83 horse-power. The acceleration in starting is ½ metre per second-second. A master controller, with Thomson-Houston "contactors," as previously described, is employed. The current collectors are cast-iron shoes held down on the rail by their own weight only, and dragged along by nearly horizontal slackly-pinned links.

11. The largest and most important electric railway in Berlin is called the "Hoch- und Untergrundbahn," or "Elevated and Underground Railway." It has been carried out by Messrs. Siemens and Halske. As long ago as 1891, Herr Werner v. Siemens proposed

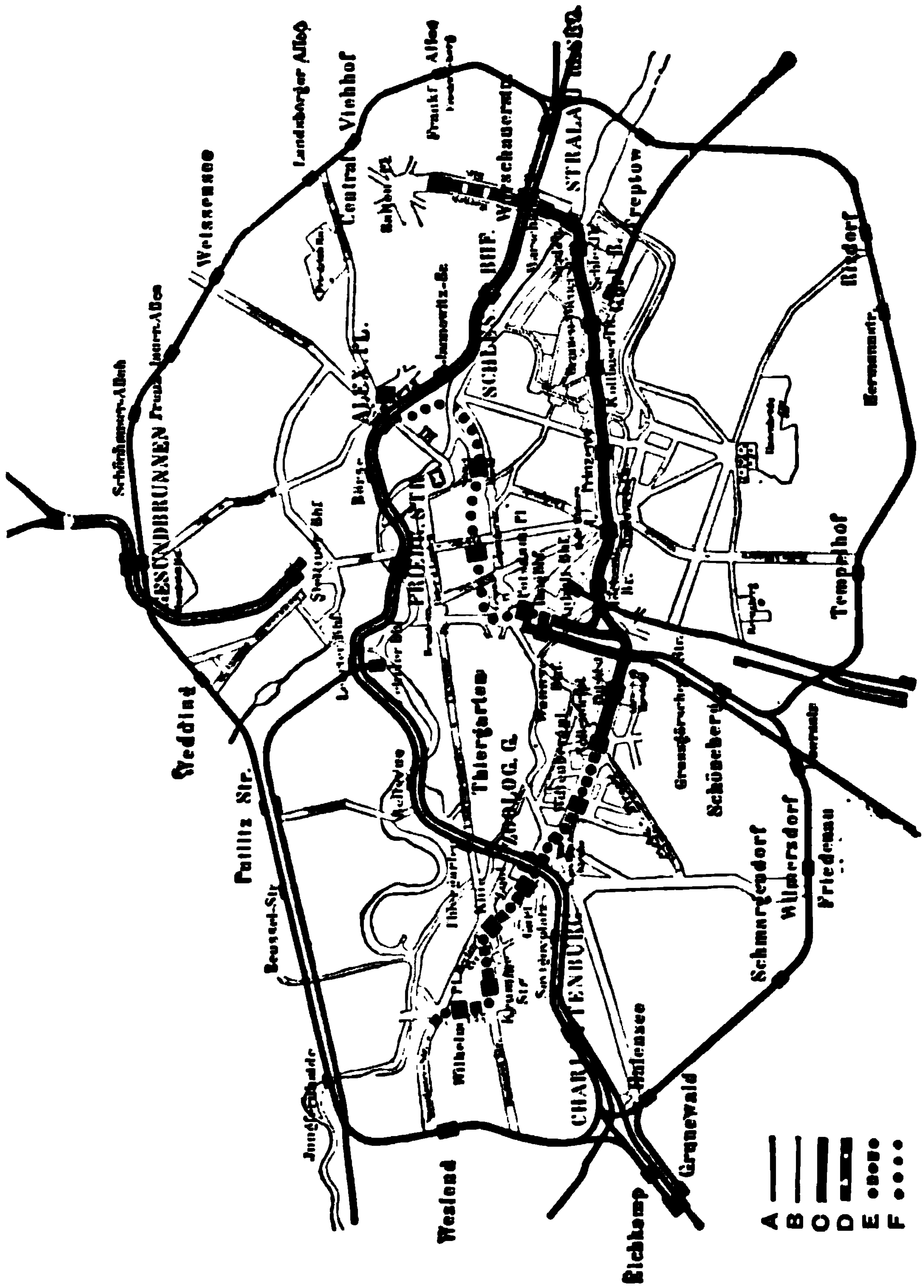


FIG. 216.—Elevated and Underground Railway, Berlin.

A. Ring and Stadt Railway.
B. Main Railways.
C. Elevated Electric Railway.
D. Surface Electric Railway.
E. Underground Electric Railway.
F. Projected Underground Extension.

what was nearly the same project as has now been carried out, and in 1893 he obtained the Imperial sanction to it. Objections raised by the municipalities and other bodies concerned led to very prolonged negotiations and delays; and it was not until January, 1899,

that these were finally brought to a successful issue. The company created to undertake the work was formed in 1897; but one portion of the line had already been begun in September, 1896. The construction was finished in December, 1901, and the line opened for public traffic in February, 1902.

This line stretches from Charlottenberg in the west to Stralau in the extreme east of Berlin, running through the southern and denser half of the city. In 1897 another underground line was projected, leading from Kreuzberge in the extreme south past the great circular Place of the Belle Alliance, where many main streets meet, along the line of Friedrich-strasse, crossing under the Unter der Linden, out by the Oranienburger Thor to Humbolthaine in the extreme north. Owing to persistent opposition in high quarters, however, this project has not yet been carried out; and Berlin still remains without any convenient north-south means of rapid transit.

The map (Fig. 216) shows the Circuit Railway, or Ringbahn, cut across by the Centralbahn, or Stadtbahn, as an east-west diameter, following nearly the line of the river Spree. These suburban and urban railways, worked by steam, have been in existence for a considerable number of years. The new electric railway does for the southern half of the city what the Stadtbahn does for its northern half.

12. When opened in 1902, the route-length of the line was 10·14 kilometres, or 6⅓ miles. This stretches from the Zoological Gardens on the west to the Warschauer Bridge over the Spree on the east, and includes the branch into the Potsdamer Bahnhof. As the map shows, this has been extended westwards to Wilhelm Platz in Charlottenburg. On the east also a surface continuation has been built to the Central Viehhof, or Cattle Market, on the Ringbahn. There is also proposed an underground extension from Potsdamer Bahnhof to the Alexander Platz on the north side of the river, as shown by round dots on the map. With these extensions, the total length will be about 20 kilometres in all.

13. The construction has been very costly, involving 7300 metres length of iron and steel viaducts and bridges, 960 metres of masonry viaducts and bridges, 1700 metres of tunnel, and 570 metres of retaining wall. The original contract price for the whole work was 15¼ million marks, exclusive of about 8 million marks spent on purchase of ground and house property. It is understood that the actual cost has been about 30 million marks, or £1,500,000.

14. The rail gauge is 1435 millimetres, or the standard 4 feet 8½ inches. The smallest curve-radius is 80 metres, this being involved in circling round the Kaiser-Wilhelm-Gedächtniss-Kirche, near the Zoological Gardens, to avoid endangering the foundations of this church. Several steep gradients are incurred in passing from the

Fig. 217.—Junction-triangle outside Potsdamer Station.

overhead to the underground construction, the steepest being 1 in 32. The steepest grade on a curve is 1 in 38. The whole dip from the highest to the lowest point of the line is 19·22 metres. About one-quarter of the whole length is curved.

There are thirteen stations from Warschauer Bridge to the Zoological Gardens, varying in distance between them from 340 to 1940 metres, the average distance apart being 920 metres. The stairs up to the stations of the overhead part of the line average 6·6 metres in height, and those to the underground station-platforms average 3·9 metres. The clear headway required at all street crossings is 4·55 metres, while 2·8 metres above the ground is required at all other places. The whole of the line is double track.

The east-end station at Warschauer is contiguous to the station of the same name on the Stadt railway, the two forming an exchange point between the two lines. From here westwards to the Potsdamer station, and on to Nollendorf on the confines of Charlottenburg, the railway is an overhead construction. This was not permitted through the Charlottenburg district, so that at Nollendorf the line dips at the grade 1 in 32, and the remainder of the western part of it is built as a shallow underground line. At the Potsdamer station, also, in order to deliver passengers direct on to the main Platz here, the line runs underground, the platforms being, in fact, under the cab and carriage yard of the main railway.

From the map it may be seen that the Ringbahn has also a branch leading up to this same Potsdamer Platz, so that there are now situated here three railway stations, (1) of the main railway to Dresden and Magdeburg, (2) of the Ringbahn, and (3) of the electric railway.

From this underground station it rises at a gradient 1 in 38 alongside of the branch of the Ringbahn. This rapid rise enables it to pass over the Königin-Augusta-strasse, which runs along the north side of the Landwehr Canal, as an overhead viaduct. Just south of this is formed a triangle, from the base of which the east and west lines stretch. Trains starting westward from Potsdamer Platz reverse at the westward terminus, and run through the base of the triangle direct to Warschauer Brücke. Here they reverse again and run back to Potsdamer Platz. Another service of trains reverse this route, and thus all three sides of the triangle require to be double track. It was imposed as a condition of the construction of this triangle that it should contain no level crossings. In order to avoid these, in starting southwards out of the Potsdamer station, the right-hand track rises at first rapidly, while the left-hand track keeps level until the former is high enough to pass over the latter. At this point each track branches, the two branches of the right-hand remaining level, while the two branches

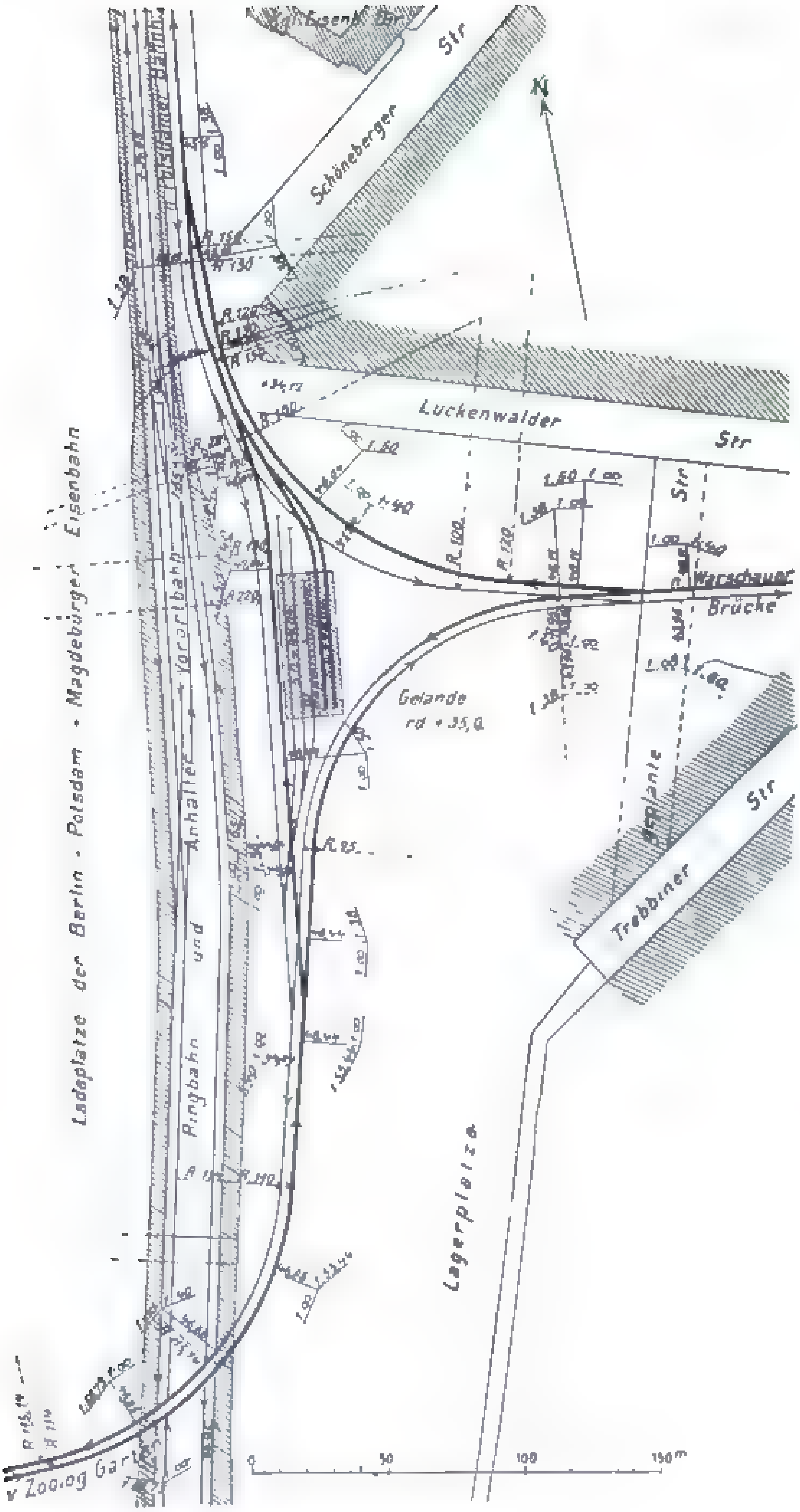


FIG. 218.—Junction-triangle over Main-line Goods Station.

Fig. 219.—Electric Railway over Anhalter Railway and Landwehr Canal.

of the left-hand climb rapidly to the same level as these right-hand branches, the westerly left-hand track passing under the easterly right-hand track. This peculiar and, indeed, unique construction is shown in perspective view in Fig. 217 and in plan in Fig. 218. This construction is repeated at each of the three corners of the triangle. In Fig. 217 one looks from the east end of the triangle with the branch to the Potsdamer station to the right, and the Warschauer line appearing in the front of the photograph. In Fig. 218 are marked the different levels, gradients, and radii of curvative of the various parts of this interesting work. The building of this part of the line is complicated by its being built over the ground of the Dresden main railway, while immediately beyond the triangle the western branch has to pass over not only the Ringbahn, but also the very extensive outer Potsdamer goods station and yard. Not far from here the eastern branch has to pass over the canal, two streets, and the Anhalter railway at the same place, and therefore one above the other, the crossing being made more difficult by the small angle of only 34 degrees which it makes with the canal. This crossing is shown in Fig. 219. Between the north end of the triangle and the Potsdamer station it has again to pass over the canal.

In crossing the outer Potsdamer station no less than twenty tracks have to be bridged over at an acute angle, necessitating a span of 142·3 metres, or 467 feet, and only a single mid-pier in this span was allowed. This pier divides the whole span into parts 61 and 81 metres wide. Furthermore, it was demanded that, in order to provide for future possible shifting of the main-railway tracks, this mid-pier should be built so that it can be moved to one or other side of its present position if this be required, the range of possible movement being 9 metres, or 30 feet. Moreover, this mid-pier must be parallel to the under-tracks, and therefore inclined at 70 degrees to the electric-railway bridge. Such being the conditions which loving Prussian co-patriots impose upon each other's work, it was no wonder that it occupied many years to complete the negotiations which made this electric railway possible. The condition was, however, accepted, and this unreasonable requirement has been met by the genius of German bridge-designers. Under the longitudinal main side girders, throughout about 10 metres length, the structure is greatly strengthened and stiffened by extra heavy girders built into its structure, with several massive cross girders both under the trackway and overhead. The under-surfaces of these auxiliary longitudinal girders are finished by smooth-planed plates bearing upon the top plates of the pier. If the pier has actually to be shifted in future, its upper and lower ends will be capable of being thrust horizontally by a number of powerful hydraulic rams

taking their abutments upon the overhead girders and upon the foundation masonry.

In this part of the structure there are no less than four tiers of railway at different levels: first, the rails of the main Dresden and Magdeburg lines; second, those of the Ringbahn; and then the two levels of the electric railway.

After leaving the triangle and crossing the above-mentioned railways and canal, the eastern and western branches of the electric railway follow, for the most part, the centre-lines of the main streets. At certain places there are peculiar difficulties to be overcome, which are evidence of the hard bargaining that is practised in Berlin. In two instances the railway goes straight through large houses without cutting away a foot more of the house structure than is absolutely

FIG. 220.—Viaduct at Kottbuser Thor.

needed for passage; the basement and ground floors are left untouched, as are also the two upper floors!—in each case the house being simply tunnelled through at mid-height. These houses are in the Dannewitz and Bülow streets.

15. Figs. 220, 221, and 222 illustrate the appearance and construction of the elevated portion of the railway in three different parts of it; while the general appearance of one of the overhead stations is seen in Fig. 223. The methods of erection employed were in many parts very interesting; but these constructive details belong to the subject of civil engineering, and are not entered upon here. The illustrations prove that an elevated railway need not, at least, be so hideous an eyesore as that which disfigures the streets of New York. Fig. 224 shows that great pains have been taken throughout to maintain the architectural character of the surroundings through

FIG. 221.—Berlin Overhead Viaduct along Landwehr Canal.

which the railway passes. In furtherance of this aim, at the Nollendorf station the railway company has erected a dome over the station building which, ornamental in itself, forms an architectural centre to the Platz and to the streets which radiate from it.

16. In the Charlottenburg district a great deal of water had to be contended with at much cost in the excavation of the underground tunnel. Here most of the houses are built on piles, there being a great deal of shifting sand, and much expensive piling was necessary in building the tunnel. It is throughout a "shallow" underground, and the excavation was nearly all "cut-and-cover" work. A depth of 0·7 metre is allowed above the ironwork to the street surfaces,

FIG. 222.—Viaduct in Bülow Strasse.

this permitting of the planting of trees alongside the roads. From the street surface to the underside of the roof-girders is 1·2 metre in depth. Below this level the station platforms are 2·46 metres, and the rails 3·33 metres. The width of the tunnel is $6\frac{1}{4}$ metres, widening to 12·64 metres at stations.

Figs. 225 and 226 show the cross and longitudinal normal sections of the tunnel, while Figs. 227 and 228 give those at a tunnel station. The roof is formed of cement-concrete transverse arches of $1\frac{1}{2}$ metre span, and 140 millimetres thick at the crown, with 200 millimetres rise. These are built over I-section cross-girders 340 millimetres deep, which are embedded in the concrete. Besides their end

bearings on the concrete walls, these cross-girders have a central bearing on a longitudinal I-girder 500 millimetres deep. This longitudinal girder is carried by central columns spaced 4½ metres apart; but this girder is not continuous. As seen in Fig. 222, it is in lengths 6½ metres long, each supporting three 1½-metre concrete arches between two columns, and two 1-metre concrete arches beyond the columns. Between the ends of each pair of longitudinal girders comes a 1½-metre concrete arch. This construction is economical, and gives the greatest freedom attainable for differences in temperature expansion between the iron and the concrete. Fig. 229 gives a very clear perspective view of this design, photographed before the concrete arches were built in. The roof is estimated to be strong enough to carry overhead street traffic comprising 20-ton waggons

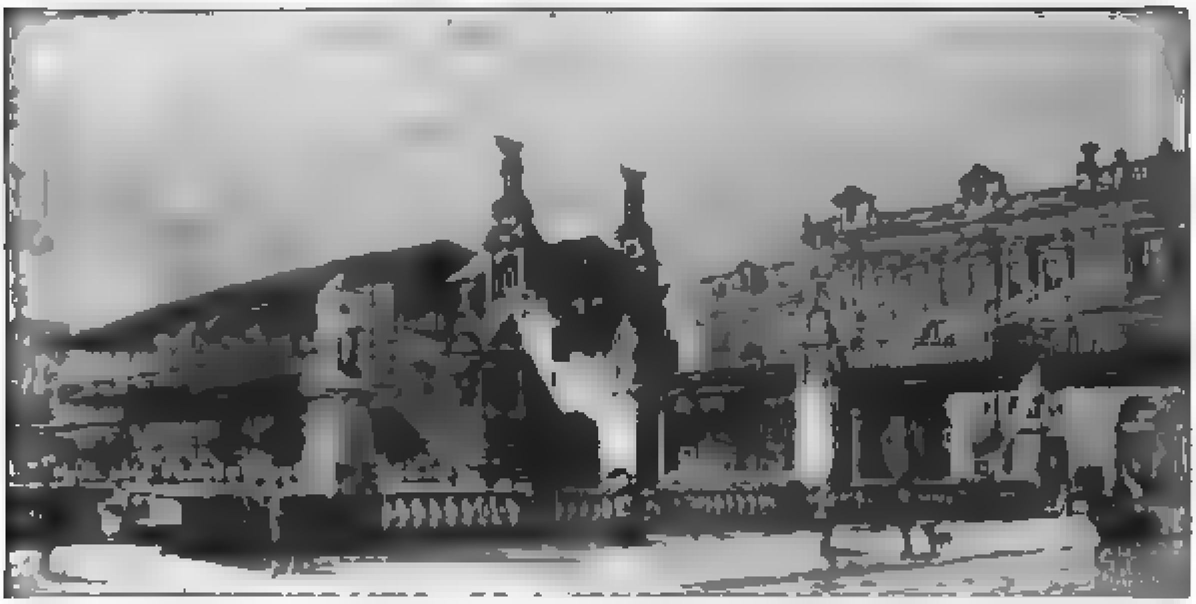


FIG. 223.—Berlin Viaduct at Hallesches Thor.

and 23-ton road-rollers. The beton foundation-floor and walls are made watertight by three separate layers of asphalte carried ½ metre above water-level, with one such layer carried to the top and over the roof. Outside the beton walls 5-inch square timber piling is driven, for which is substituted iron I-section piling in the curve that encircles the Kaiser-Wilhelm-Gedächtniss Church. To carry off leakage and rainwater, a drain is carried along the centre of each track. The walls of the stations are lined with white glazed tiles.

17. Figs. 230 and 231 give sections of the track-rails used, the first in the tunnels, and the second on the overhead viaducts. The latter require greater strength because of the greater spacing of the cross-sleepers. The one is 115 and the other 180 millimetres deep, and they weigh 25½ and 47¼ kilograms per metre respectively. Both these rails are laid in 12-metre lengths.

Fig. 224.—Elevated Railway at Oberbaum Bridge and Stralauer Thor, Berlin.

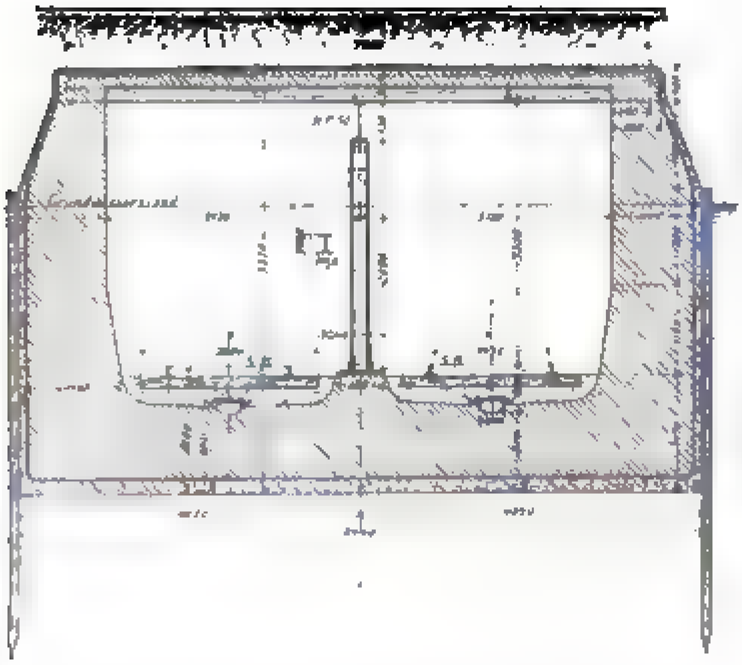


Fig. 225.—Normal Tunnel—Cross Section.

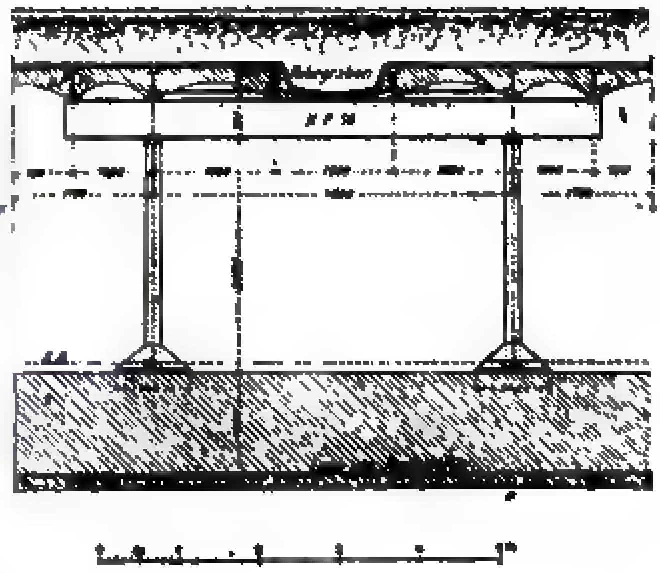


Fig. 226.—Normal Tunnel—Longitudinal Section.

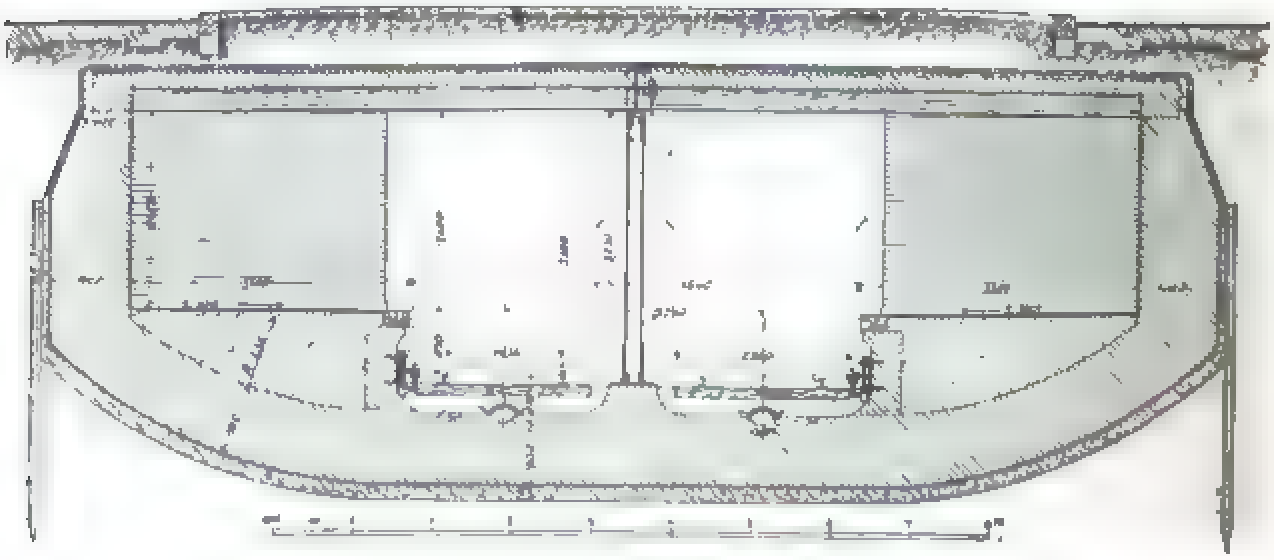


Fig. 227.—Station Tunnel—Cross Section.

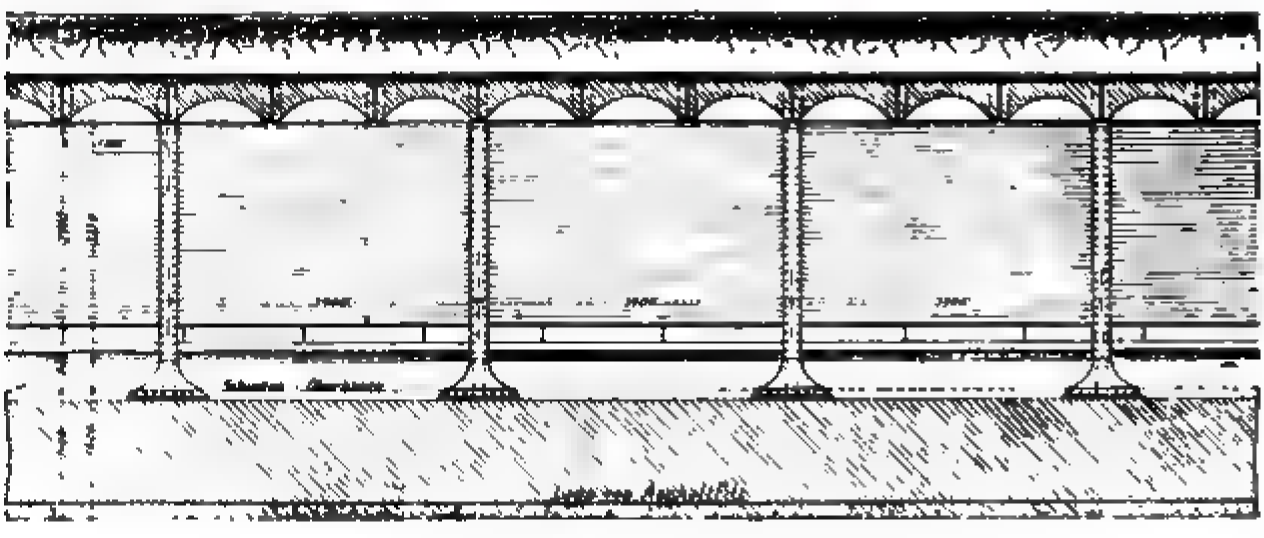


Fig. 228.—Station Tunnel—Longitudinal Section.

18. Each normal train is composed of three coaches, of which the middle one is a trailer and the other two motor-cars. The extreme height of each coach is 3·18 metres, and its extreme breadth 2·36

FIG. 229.—Shallow Underground Electric Railway, Berlin.

metres; with a body 12 metres long and 12·7 metres over the buffers, and 7½ metres between the swivel-pins of the two bogie-trucks. The wheel-base of each truck is 1·8 metres. The wheel diameter is 0·85 metres. Each carriage has two opposite side doors at each end, that

at the front end being the exit, and that at the back the entrance. There is a driver's cabin at each end of the train, entirely partitioned off from the public saloons. The train of three coaches is seated for 122 passengers, and is lighted by 36 electric lamps. The motor-coach weighs, when fully loaded, 26 tons.

Each motor-coach, as at present built, carries three motors; but the design of the truck allows a fourth to be added as soon as this is found to be needed, when, also, it is intended to add another trailer-car, making the train a four-coach one. The motors are 4-pole and are geared, with spring-nose suspension, each of 71 rated horse-power. Each motor-coach carries two sliding collector-shoes, and is furnished with hand, air-pressure, and emergency electric brakes.

The railway has started with a 5-minute service of trains, but this is to be increased to a $2\frac{1}{2}$-minute service in the future. At

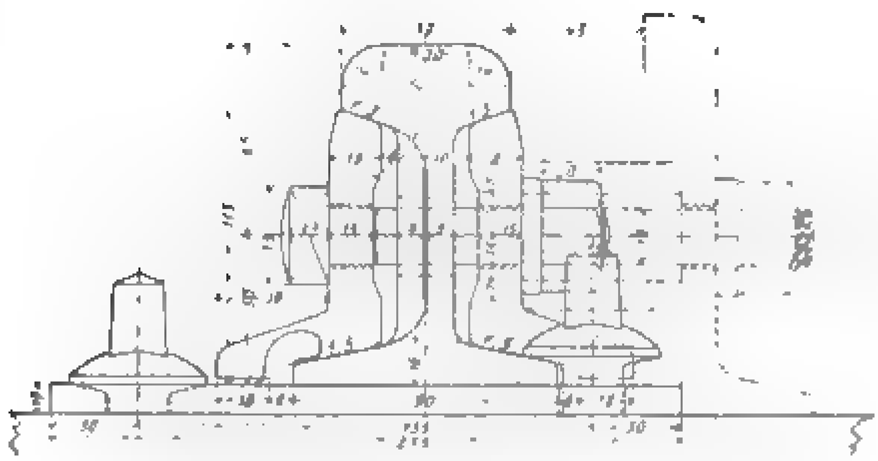


FIG. 230.—Berlin Underground Rail Section.

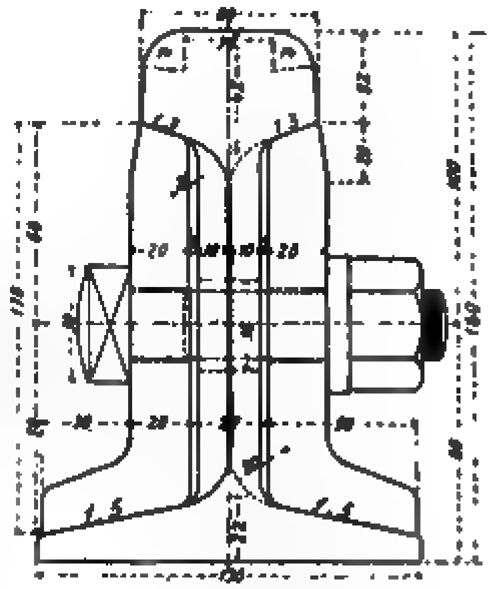


FIG. 231.—Berlin Overhead Viaduct Track-rail.

present the service is maintained with a rolling-stock of 56 motor-coaches and 28 trailer-cars, sufficient for 28 normal trains. The maximum velocity is 50 kilometres per hour; the mean, exclusive of stops, about 40 kilometres, and, including stops, 30 kilometres per hour.

19. Fig. 232 gives a section of the power station, which is situated close to the outer Potsdamer station on the eastern, or Warschauer, branch. In the basement are installed the surface condensers and the feed and air pumps. On the ground floor are placed the engines, dynamos, and switchboard. Above these are situated the boiler-flues and tramway for removal of ash and clinker; and above these again comes the boiler-house. Above the boilers, in the roof, is situated the coal-bunker.

There are six water-tube boilers, each of 230 square metre heating

surface, with extension room for four more similar boilers. The boiler pressure is 10 atmospheres, and the steam is superheated to 225° C. Two feed pumps, each of 40 cubic metres per hour capacity,

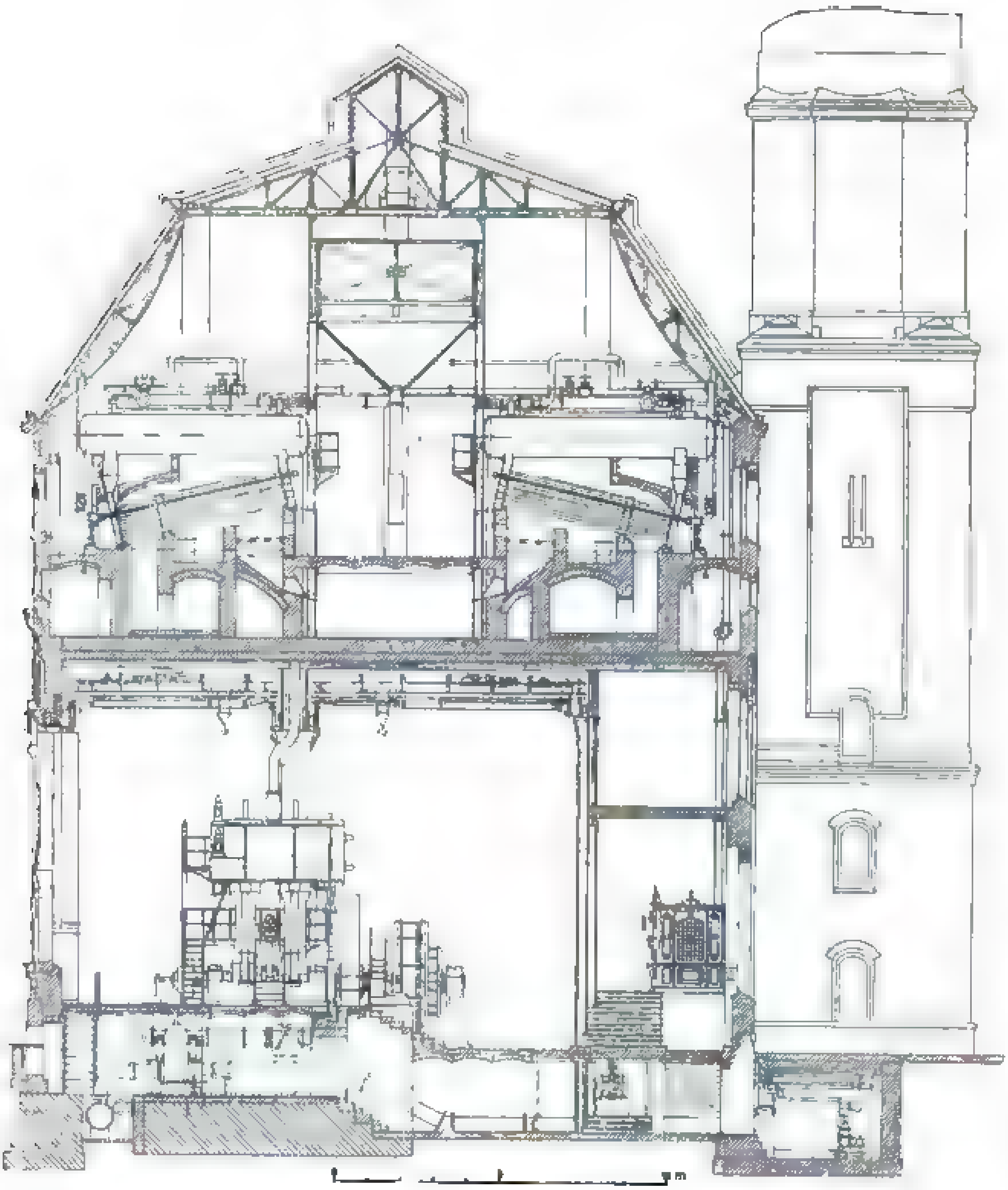


FIG. 232.—Berlin Power-house.

serve the six boilers, the make-up water being taken from the Landwehr Canal.

There are three vertical compound steam-engines, each of 900

normal horse-power, with 30 per cent. overload capacity, built by Borsig and Co. Space is provided for two other engines of 1200

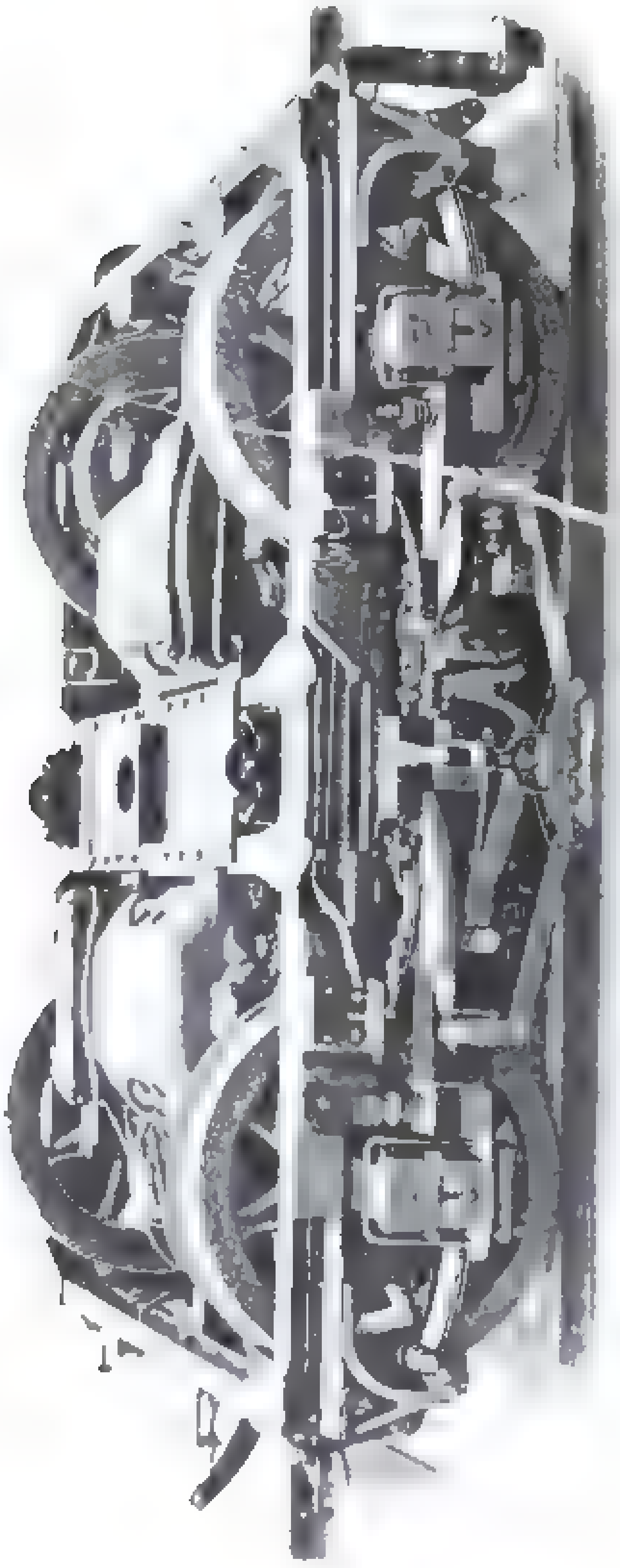


Fig. 233.—Bogie-truck and collector-shoe.

horse-power, and the building is arranged for extension to give place for still two more. These engines have cylinders 800 and 1270

millimetres diameter by 750 millimetres stroke, with Corliss valve-gear, and run at 115 revolutions per minute. Each has a 30-ton fly-wheel, and has electro-motor starting gear.

20. The electric energy is generated as continuous current at 750 volts. The dynamos, each of 800 kilowatts and compound-wound, are built by Siemens and Halske. There is one to each steam-engine, direct coupled. Each is supported by a buffer battery, and

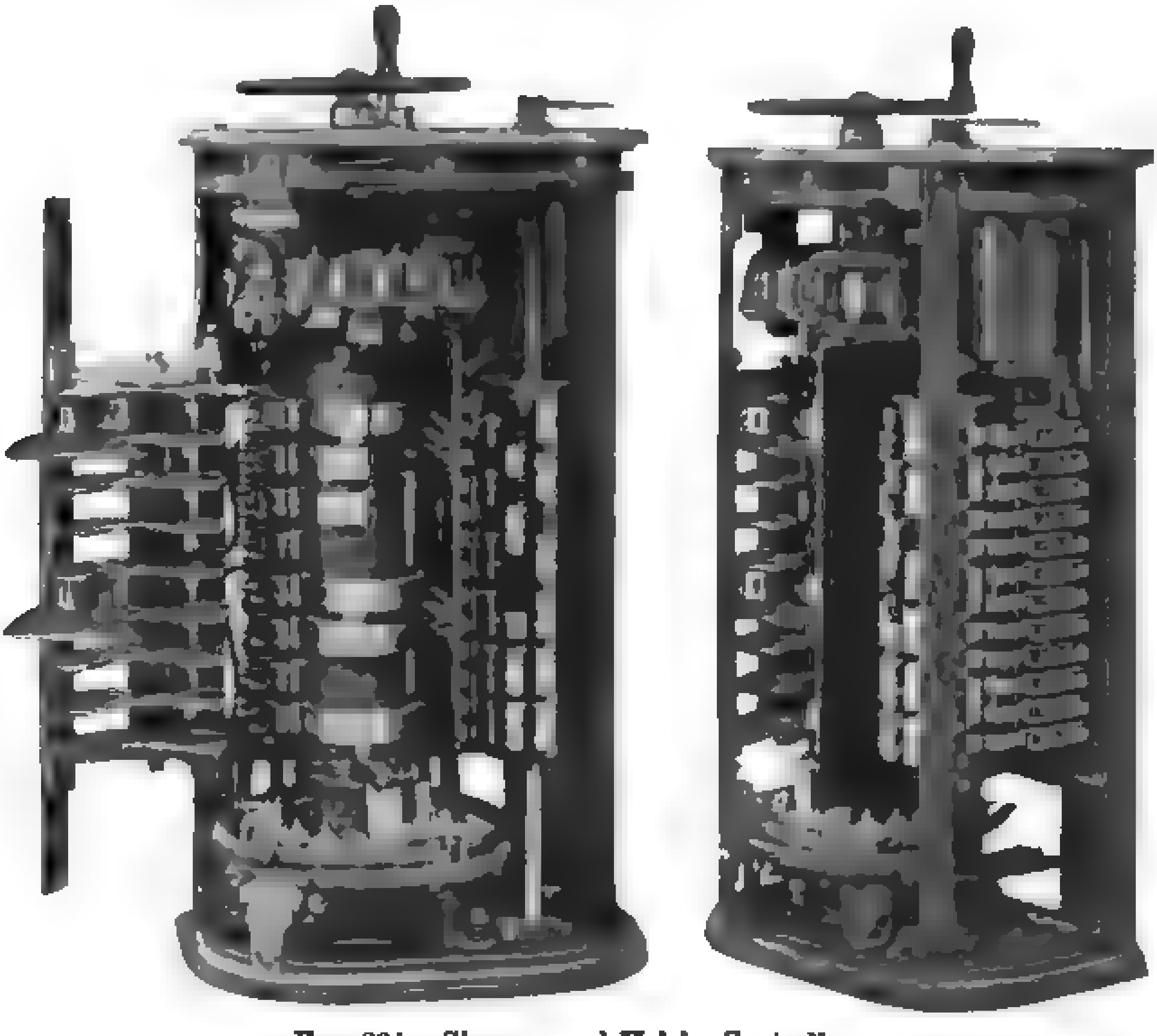


FIG. 231.—Siemens and Halske Controller.

each machine and each feeder is protected by fuses. A special accumulator battery is installed for the lighting service.

The return current is by the track-rails, and the supply is taken by two Vignole third rails on insulators. On the overhead viaduct the two third rails lie between the two tracks, but in the tunnels they lie on the outsides of the tracks. The reason for this difference is, that on the former the ways for the track-layers and linesmen are on the outside, while in tunnel there is a single central way for the workmen, this central way being to a considerable degree protected

by the central columns. These conductor-rails are protected by a timber plank-guard along each side, and are well copper-bonded. On the viaduct the conductor-rail lies 180 millimetres higher than the track-rails, and in the tunnel the difference of level is 230 millimetres. Thus each motor-coach carries four collecting-shoes, and each train, with two motor-coaches, eight collecting-shoes.

Fig. 233 shows very clearly both the general construction of the two-motor bogie-truck used on this railway and also the slightly complicated linkage by which the collecting-shoe is suspended from a timber beam stretching between the two axle-boxes. By means of the lever seen to the left of the centre, the shoe may be lifted off the rail by the driver operating from his cab.

Fig. 234, which gives two views of the controller used on the line, illustrates very well the Siemens and Halske design of this apparatus.

CHAPTER X

ITALIAN DIRECT-CURRENT RAILWAYS—ELBERFELD MONO-RAIL

1. Development of Electric Traction in Italy—2. Milan-Gallarate-Ceresio Direct-current Railway—3. Elberfeld Suspended Direct-current Mono-rail—4. Ditto, Arch-trusses and Track-girder—5. Ditto, Truss-foundations and Temperature Expansion—6. Ditto, Side-swing of Train in rounding Curves—7. Ditto, Design of Track-girder—8. Ditto, Car Suspension and Motor-truck—9. Ditto, Conductor-rail and Contact-shoe—10. Ditto, Cars and Train Service—11. Ditto, Energy Supply and Central Power-station—12. Ditto, Block-signal System—13. Ditto, Stations and Loops—14. Ditto, Cost of Construction and Equipment.

1. THROUGHOUT Europe nowhere has electric traction spread more rapidly or more usefully than in Northern Italy. Italy labours under the great disadvantage of dear fuel, there being no coal mines, and even oil fuel being inordinately costly on account of high import duties. On the railways the locomotives burn, to a large extent, "briquettes," much to the discomfort of the olfactory and optic nerves of the passengers. On the other hand, all along the southern foot-slopes of the Alps, as also among the Apennines, there is great abundance of water power. In Rome power from the famous Tivoli waterfalls has for long supplied electric light to the city; and, as early as 1895, under the skilful scientific guidance of Ingegnere Professor Mengarini, an extensive tramway system was superadded to the same power-station. The load was very successfully levelled and steadied by a storage battery of great capacity, switched into circuit in sections by an automatic wheel-regulator of large diameter operated by a shunt from the outgoing current.

The industrial population of Lombardy, in especial, has for many years made great use of horse and steam tramways and "economic railways." These are now being largely electrified. As an example may be cited the Lugano Street Railway, which was converted to electric traction in 1896. The line is 3 miles long only, with gradients from 3 to 6 per cent., and it is fed from a water-power station $7\frac{1}{2}$ miles distant. A horizontal-shaft turbine of 300 horse-power is direct-coupled to a 3-phase alternator with rotating field and fixed armature,

generating current of 40 per second frequency at 5000 volts, and running at 600 revolutions per minute. The transmission is by two overhead naked wires 5 millimetres in diameter, and at a single sub-station the energy is transformed to 400 volts 3-phase. Small cars of 24 seats are used, each driven by one 20-horse-power 3-phase motor. Two overhead trolley wires, each 6 millimetres diameter and 10 inches apart, carry two of the phases, while the third goes by the earthed running-rails. The average speed of 9¼ miles per hour is maintained.

On this line trials with secondary batteries carried on the cars had been made. It was found that with them 19 horse-power per car was consumed at the power-station, whereas with the trolley and 3-phase motors only from 10 to 12 horse-power were used, while also the positive plates of the batteries did not last more than three to four months.

During the last eight years there has been an enormous development of electric tramway traffic in and about Milan. Here the great square in front of the cathedral, up till a few years ago never desecrated by the passing even of a steam traction-engine, is now the centre from which radiate half a dozen tram routes, and is for 18 out of the 24 hours blocked by a double ring of 50 or 60 electric cars manœuvring a way into, through, and out of the Piazza. Most of the power for this great traffic is brought a distance of 34 kilometres (21½ miles) from a central generating station at Paderno, where there are installed seven 2200-horse-power 3-phase generators by Brown, Boveri and Co. The transmission is at 15,000 volts, which tension is produced in the armatures of the generators without step-up transformers.

2. The most important direct-current railway in this neighbourhood is that from Milan, through Gallarate, to Porto Ceresio, at the south end of the Lake of Lugano, with branches from Gallarate to Laveno, on Lake Maggiore, and to Arona on the west shore of the same lake. The lengths are, from Milan to Gallarate, 40 kilometres; from Gallarate to Porto Ceresio, 33 kilometres; Gallarate to Laveno, 31 kilometres; and Gallarate to Arona, 26 kilometres; a total of 130 kilometres, or 81 miles. From Milan to Gallarate is double track, and the rest single. The maximum gradient is in descending to Lugano near Porto Ceresio, where it is 1 in 50; and 1·0 to 1·2 per cent. grade occurs at several places. The curvature is generally easy, only five curves of 300 to 400 metres radius occurring in the whole length. There are 28 stations on the line, the average distance apart being 4·65 kilometres, or 2·9 miles.

The power is taken from the river Ticino at Tornavento, about 7 miles away from the railway line. 11,000 horse-power turbines are direct-coupled to 3-phase alternators, giving 12,000 volts. There

FIG. 235.—300-feet Curve on Suspension Mono-rail.

are seven sub-stations, spaced nearly equally apart, where static transformers bring down the voltage to 420, and rotary converters change the energy to 650-volt direct current. This is taken along the line by an insulated third-rail laid to one side of the track. On the double track the two third rails lie between the two tracks, and at all stations and crossings each is protected by two heavy timber plank-guards. The current is collected by cast-iron sliding-shoes kept down on the rail by their own weight alone. The coaches are each on two bogie-trucks, each truck carrying two 150 horse-power motors geared in the ratio of 3 to 1, with driving-wheels 1030 millimetres, or 41 inches, in diameter. The motor-coach has 63 seats, and weighs 40 tons empty. The trailer-cars, which weigh 27 tons empty, are also seated for 63, and have platforms giving considerable standing room. The maximum speed attained is 90 kilometres, or 56 miles, per hour. The mean speed between Milan and Gallarate is 44, and that over the whole line 28, kilometres per hour.

This line belongs to the "Mediterranean Railway Co.," which is one of the two railway companies owning all the lines from Turin to Trieste throughout the north of Italy, as well as the most important lines as far south as Rome. The other company is called the "Adriatica," and this other has equipped a high-tension line along Lake Como, which will be described in the next chapter. These two electric installations are experiments of the very highest importance. They have been carried out with the view of ascertaining whether it be desirable to electrify the whole of the main lines between Turin, Milan, Florence, and Venice, and, if so, whether alternating or direct-current should be used for the electrification. The object is to maintain the railway traffic as against the competition of the new tramways and "economic" or "industrial" railways. The scheme involves the expenditure of very large additional capital in central stations—many of them with hydraulic power in which the ratio of capital outlay to working expenditure is large—and in the electrical equipment of the lines. Practically, the execution of these large works now awaits only the subscription of this necessary capital.

3. Probably the most remarkable continuous-current railway on the Continent is the Suspended Mono-rail at Elberfeld. The system was the invention of Eugen Laugen. It was applied, in the first place, to a short rope railway climbing a height of 265 feet in a horizontal length of $\frac{1}{8}$ mile at Loeschwitz, a pleasure resort outside Dresden. The running-rails are placed at the lower edges of an overhead longitudinal girder, there being one rail for the up line and one rail for the down line. The train hangs below the rail, and is suspended from it by wheeled brackets strongly attached to the roof of the coach. At Elberfeld in the bracket is pivoted a swivel bogie-truck

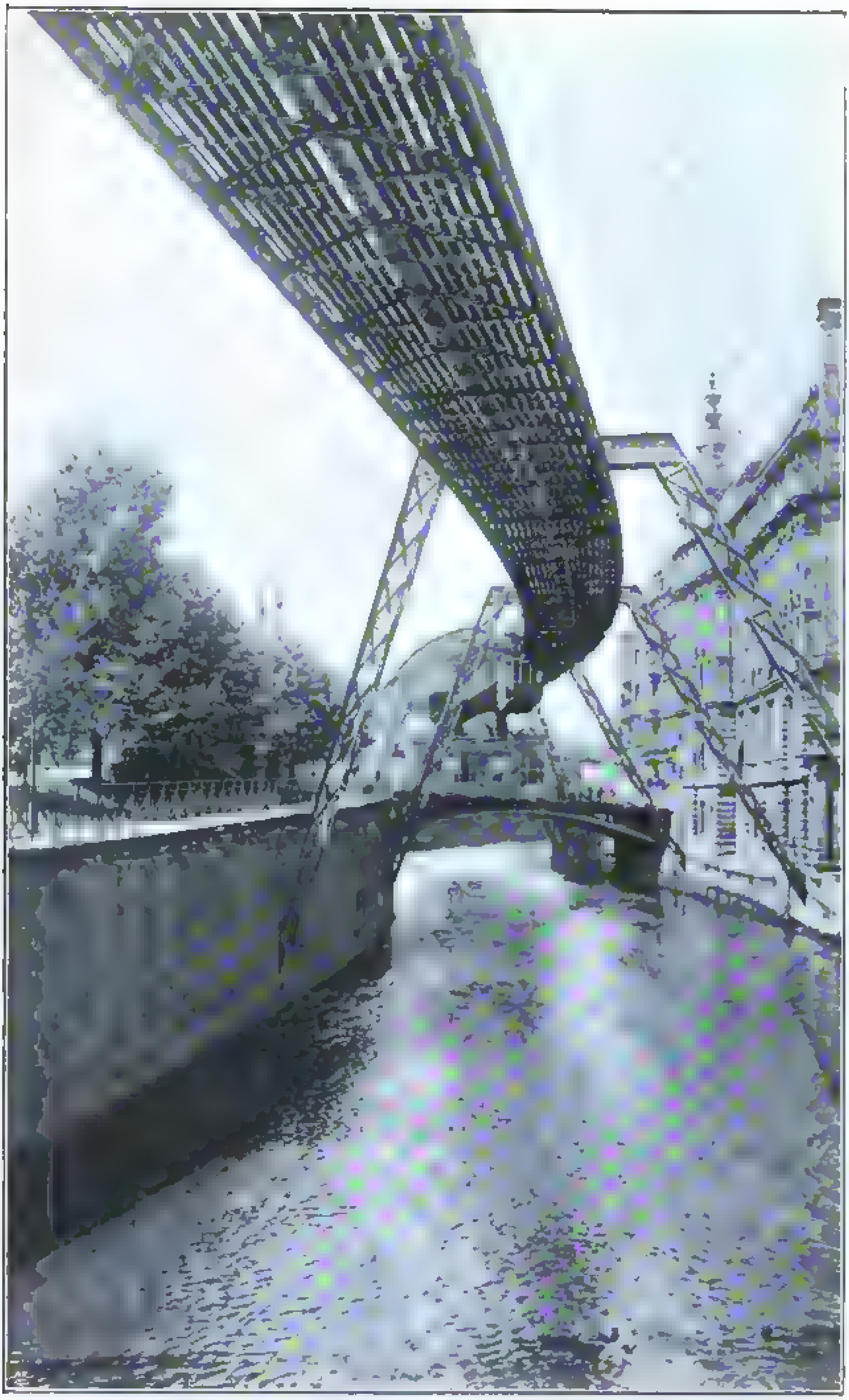


FIG. 236.—Elberfeld Suspension Mono-rail over River Wupper.

with two wheels running tandem on the one rail. One wheel on each bogie is driven by a direct-current motor, the current being collected by a sliding-shoe.

4. Figs. 235 and 236 show the appearance of the structure at two parts of Elberfeld, where it follows the line of the river Wupper at from 30 to 60 feet above the water level. Towards the western end of the railway, which is 8½ miles long, the line pursues its way over the high-road for 1½ mile. In this stretch the construction is as shown in Fig. 237. All three photographs show how the cars hang from the rail on the outside edge of the longitudinal girder. In both designs the longitudinal track-girder hangs from a series of transverse trusses. Over the river, where the height and span of these trusses are great, they are composed of two oblique latticed columns, whose upper ends are joined by, and support, a cross plate-girder. The inclinations of the two columns are seldom equal in each individual truss, and vary greatly along the line according to the height and the necessary span at ground level. Thus, in Fig. 236, in which is seen the busiest station in the centre of Elberfeld, facing the chief hotel of the town, the columns have a much steeper rake than in Fig. 235. Fig. 235 shows one of the severest curves on the line: it is of 300 feet radius. In Fig. 236 the bars seen running along the girder are a wooden plank-way for workmen engaged on repairs, which forms no part of the supporting structure. The length of the cross plate-girder of each arch-truss is determined by the necessity of allowing a train to pass under it on each side of the longitudinal girder, and the least permissible slope given to the columns depends on the angle to which the coach may swing by centrifugal force in rounding a curve. In the form used over the road the side columns are vertical box-girders, and the overhead part is a pair of quadrantal arcs combined with a straight level central portion, all built on box-girder pattern.

5. The structural details of these two forms of arch-truss used over the river and over the high-road are shown in Figs. 238 and 239. These details are interesting to the civil and mechanical engineer, but as they do not affect the electrical character of the undertaking, they will not be studied closely here. It may be noticed, however, that the bases of the columns shown in the diagrams rest on spherical foundation supports, with the object of giving great freedom for small motions due to temperature expansions. At certain intervals, however, other arches, with bases firmly anchored to their foundations, are used. The anchored arches average one to six or seven pivoted arches. These anchored arches weigh 30 tons over the river and 22½ tons over the road. The pivoted-base arches weigh from 9 to 10 tons, according to height. The average span between them is 30 metres, and for this span the track-girder supported by the arches weighs 21½ tons.

FIG. 237.—Suspension Mono-rail over Street in Sonnborn.

6. In Fig. 238 the angle to which a coach may swing laterally as it hangs on the overhead rail is shown as 15 degrees. In ordinary

FIG. 239.

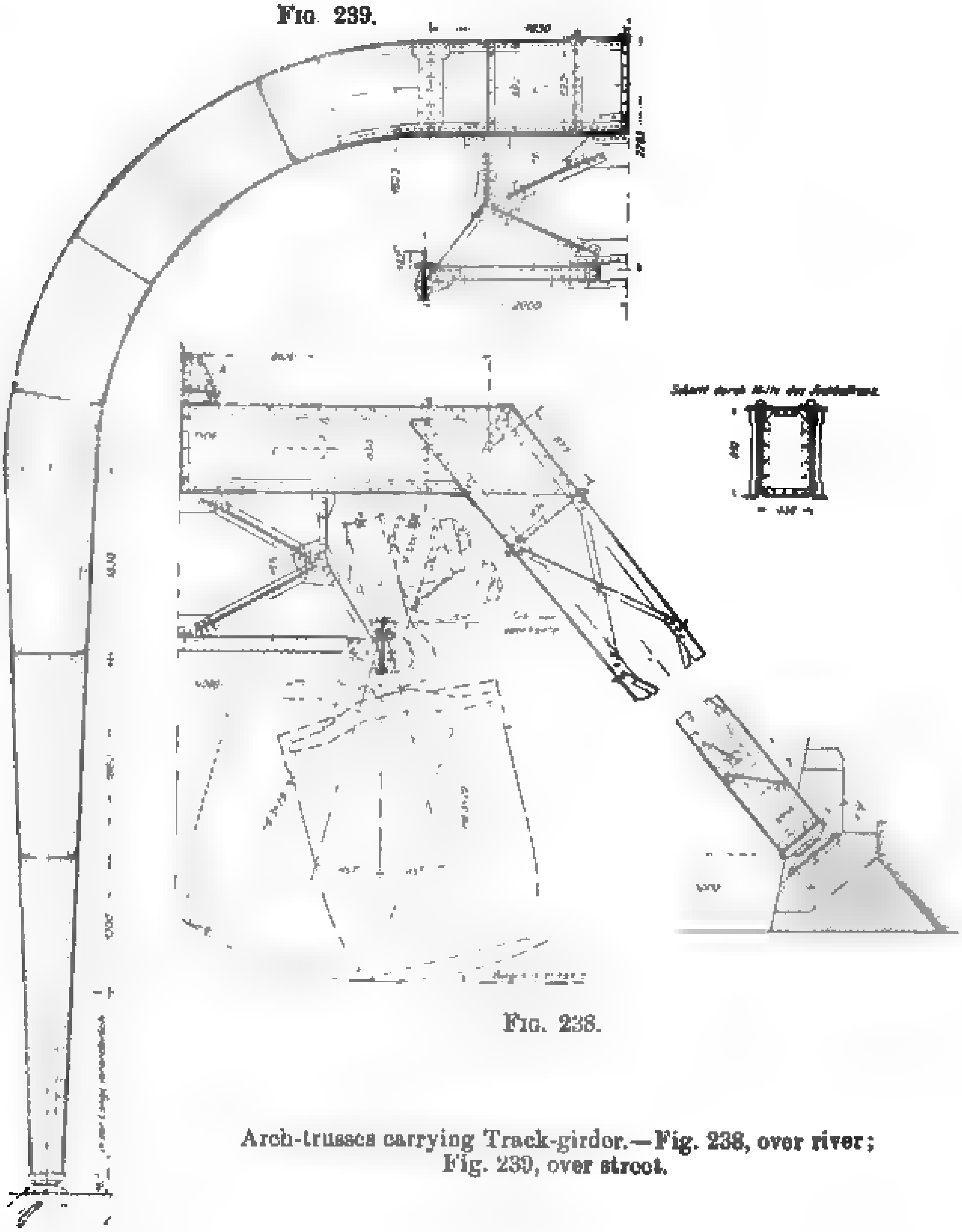


FIG. 238.

Arch-trusses carrying Track-girder.—Fig. 238, over river; Fig. 239, over street.

two-rail surface railways it is endeavoured to counteract the overturning moment on the trains due to the centrifugal force in rounding curves by what is called "cant" of the outer rail; that is, the outer is laid at a higher level than the inner rail. If W be the weight of a

coach, V the speed of the train, and R the radius of the curve, then $\frac{WV^2}{gR}$ is the overturning centrifugal force, and this divided by W, or $\frac{V^2}{gR}$ is the tangent of the angle made with the vertical by the resultant of this force and the weight W.

If the superelevation of the outer rail be made equal to the gauge multiplied by this tangent, then the pressure on the two rails will still be normal to the plane containing the two rail surfaces, and there will be no tendency to side-slip. This superelevation increases with the square of the speed, and it is easily shown that for ordinary high velocities the superelevation found by this formula would be so extravagant as to cause side-slipping towards the centre of curvature when trains rounded the curve at very slow speeds. The full superelevation corresponding to maximum speed is thus never employed. But in the Langen mono-rail suspension, in rounding curves, the coaches are free to swing to the precise correct inclination whatever the speed may be; that is, they naturally and automatically swing to such an inclination as keeps the resultant of weight and centrifugal force parallel to the central plane of the coach from top to bottom and perpendicular to the floor and to the seats. This was the fundamental idea on which Langen's invention was based. In practice it is found to harmonize generally with the mean action actually occurring, so that the riding in the cars is pleasant and comfortable; but the author's own observations on the railway indicated that the swing rarely much exceeds half that theoretically due to the velocity of the train. Upon this mean action, also, are found to be super-imposed rhythmic side swayings set up by sudden changes of curvature and by shocks occasioned by imperfect rail-joints and other irregularities in the even alignment of the rails. Among the causes of these swayings must, no doubt, also be reckoned the more or less sudden deflection of the longitudinal girder as the train passes from span to span between the arch-trusses.

7. This longitudinal track-girder is the design of Herr Rieppel, famous as a bridge constructor. It is of a form never before used in bridge building. It may be understood by carefully examining the photograph Fig. 235, and the further drawings, Figs. 240, 241, and 242. What may be called the top flange is seen in plan in Fig. 240. It is really a horizontal braced girder of 2½ metres horizontal width, and is intended to be well able to resist horizontal deflection by side-wind pressure. From the plan it may be noted that it contains no mid-rib along its centre line. To the centres of its cross-members are attached the top ends of the members of the main vertical web, the elevation of which is shown in Fig. 241. This, again, is a lattice structure, and part of it is a strong bottom boom running horizontally

to near the ends and at each end sloping upwards to the level of the top flange in the pivot-joint, where it rests upon the cross plate-girder of the arch-trusses shown in Figs. 238 and 239. This joint is at one end of the girder a single spherical joint, which leaves freedom for angular end deflection, resting upon roller-plates, which give freedom for end movement caused by temperature expansion. At the other end the roller-joint is omitted. Girders on a pair of contiguous spans have their roller expansion joint at one and the same arch-truss, and the two girders are connected by a transverse equalizing lever pivoted on the arch-truss, which compels the two to roll equal

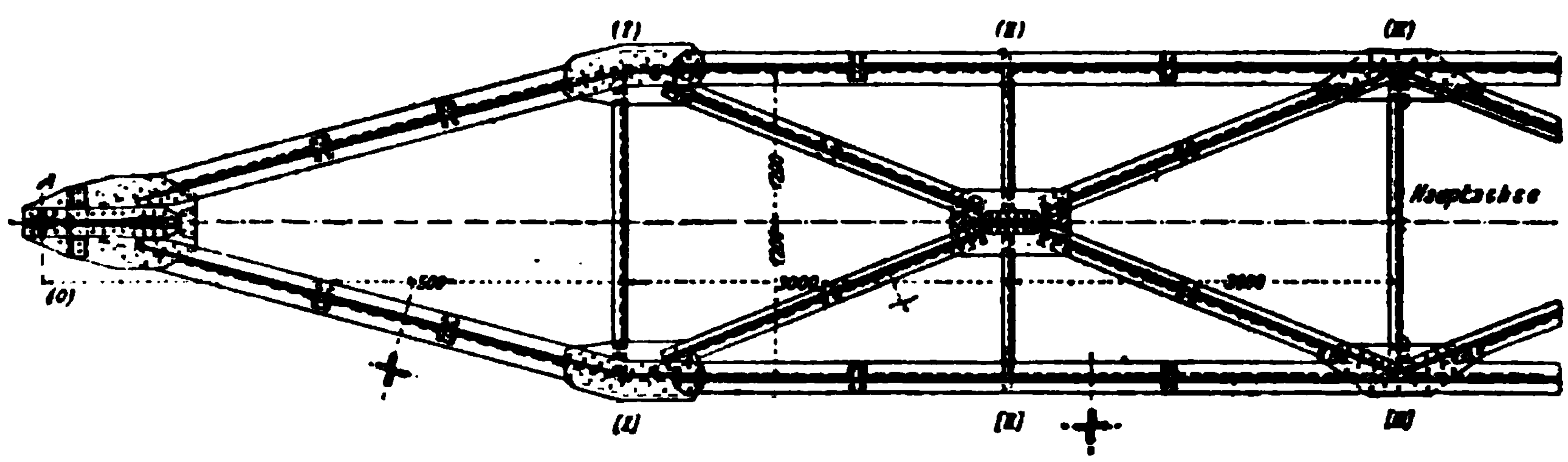


Fig. 240.—Plan of Top Flange of Track-girder.

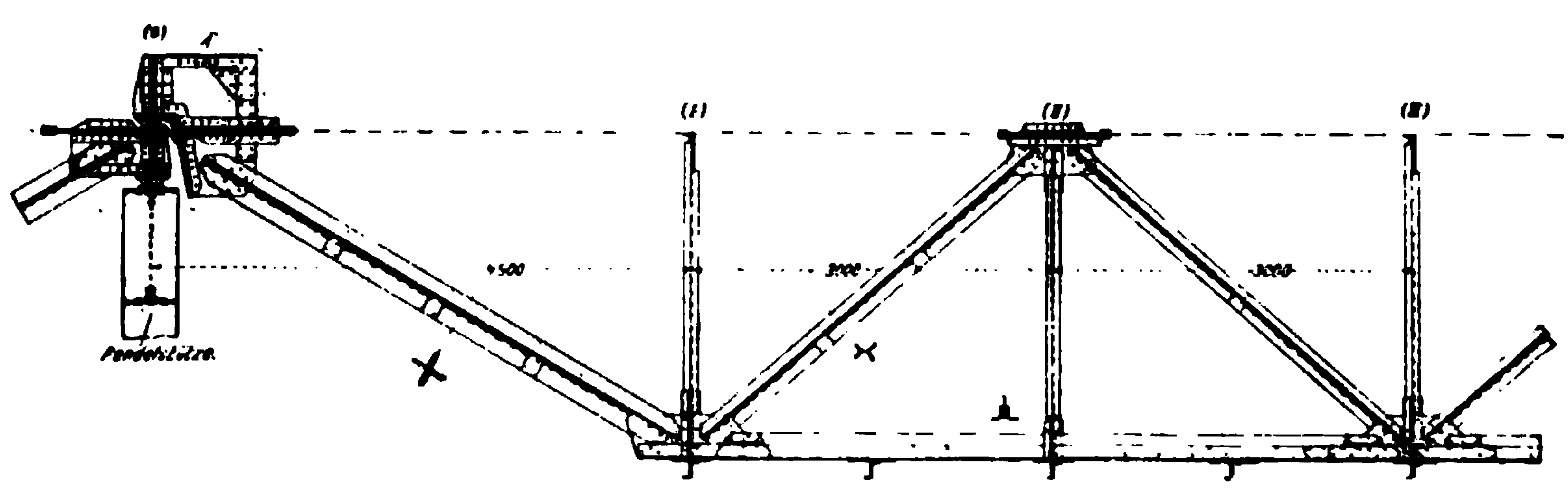


Fig. 241.—Elevation of Vertical Web of Track-girder.

and opposite distances on the roller-plate. As the top horizontal girder has no mid-rib, the vertical web-girder has no top boom to which it can transmit directly the thrusts and pulls of its diagonal braces and uprights. These are taken by the lateral booms of Fig. 240 only after being transmitted through the diagonal bracing of this horizontal girder.

This structure of top flange, vertical web, and bottom boom carries the floor, which supports the rails at its edges, by the transverse triangular hanging frames, one of which is seen in Fig. 242. The floor is also a braced horizontal girder of great lateral stiffness against bending. Besides its central midrib formed by the main

bottom boom, two 12-inch deep I-section steel girders run one along each edge. These form the flanges of the floor girder taken as a beam to resist side-wind pressure. The rails of the up and down lines are 4 metres apart.

So far as described, the whole girder would be free to swing laterally round the axis joining the two spherical joints by which it rests at its two ends on the arch-trusses. But this swinging is prevented by the floor being riveted to the trapezoidal frame, seen in Figs. 238 and 239, built under the cross-girder of the arch-truss.

Both the rails and the I-girders carrying them are given sliding expansion joints at suitable intervals. In every case the expansion joint is placed immediately under an arch-truss.

The whole structure is greatly wanting in rigidity as against deflection by twisting round a longitudinal axis. The twisting moments arise from the eccentricity of the train-load, it being hung 2 metres away from the centre line. This twist is resisted only by the stiffness of the riveted joints between the vertical web and the horizontal top girder, and these offer only an extremely feeble resistance. The removal of the strong members of the top girder from the line of the stresses which it is their chief function to bear, and the placing of the main part of the bottom boom remote from the train-load which it has to carry, are defects which might have been obviated by a simpler and more straightforward leading design and by a rearrangement of the bracing, the material and weight of which is uneconomically placed. The structure is fairly efficient in resisting side-wind pressure, but not so in respect of carrying its own weight or the train-loading. The author's measurements of the deflections caused by passing trains showed this to be so, and as these deflections have a decided influence upon the economical working of the trains and upon the comfort of the travelling, it is regrettable that the structure was not made stiffer in the performance of its main duty.

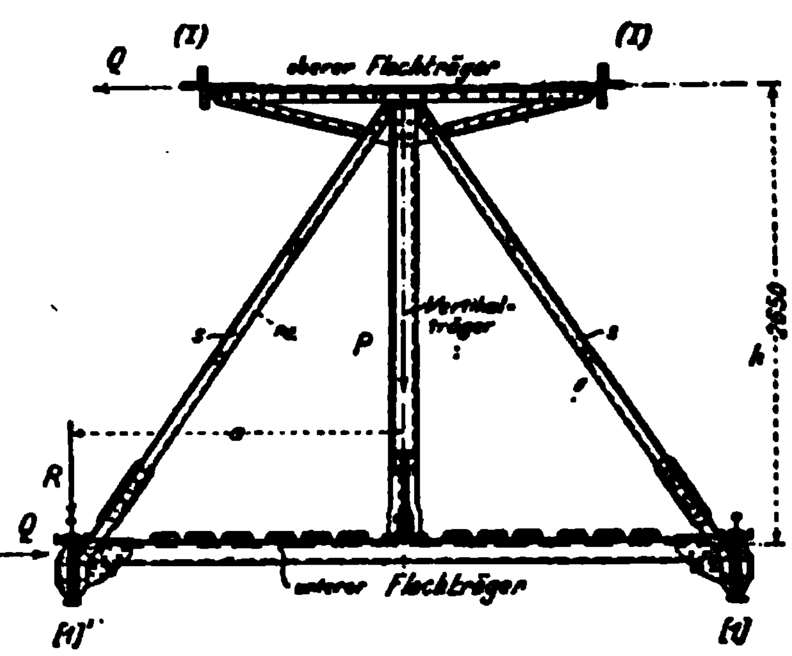


FIG. 242.—Transverse Frames, Suspending Floor and Running Rails of Track-girder.

8. Figs. 243 and 244 show the carriage suspension and motor-trucks as now used. The bogie-truck necessarily carries the wheels and the motor, but in the first pattern used the motor, which is very considerable in weight, was placed above the running-rails at the same level as the wheel axles, as may be seen in Fig. 235. As the

truck necessarily has a flexible spring jointing to the car body, it is evident that, in rounding the curves, the centrifugal force of any mass in the truck lying above rail-level will tend to tilt the truck in the opposite angular direction to that of the swing of the car and this will injuriously strain the spring joint between the two. This was undoubtedly a cause of some erratic side-swaying, and the chief engineer, Herr W. Schmitz, since his recent appointment, has substituted the design here shown.

There are two main objects fulfilled by this alteration of the original design. In the first place, the motors are now placed under, instead of over, the running-rail. It proved, however, a difficult matter to find room for the motor below the rail, as the carriages could not be lowered on account of the station platforms. Room has been made for the motors by fashioning a hollow recess at each end of the car roof.

Secondly, it was desired that the driving joint between bogie frame and car should be brought as nearly as possible to rail-level, as upon this depends the absence of jerkiness, or intermittently sudden tugging character, of the driving action. The higher this joint is above the rail, the greater is the tendency to ride on the front wheel when sudden changes of travelling resistance occur from whatever cause. It will be seen that both these objects are completely attained in the new design.

The illustration shows one bogie only. The bogies at each end are similar in every respect, except that they are right and left handed. In each bogie there are two axles, with one wheel on each axle. One axle only of each bogie is driven, namely, that nearer the middle of the car. There are thus two motors to each car. The wheel tires are 750 millimetres diameter; the travelling speed is 40 kilometres per hour; and the energy consumption is 662 watt-hours per car kilometre. At normal speed the wheels thus rotate at 283 revolutions per minute, and the mean power exerted is 26½ kilowatts, or 36 horse-power.

The bogie frame consists of an upper longitudinal box-girder, AA; a parallel trough-girder, G, just above rail-level; and a third longitudinal bottom girder, H: these three girders being stiffly bound together by two vertical girders, K, K. The three longitudinal horizontal girders lie in the vertical plane of the mono-rail. The girders K, K are cranked so as to pass down the outer side of this mono-rail, clearing it by a little over 4 inches—110 millimetres. The motor L is secured to the lower girder H, and drives, through two pairs of bevel-toothed gear and a vertical intermediate shaft, on to the horizontal axle of the driving-wheel R. The bottom girder H also carries the two safety guards M, M, which are arched to a centre coinciding with the top surface of the rail, and which fit, with a

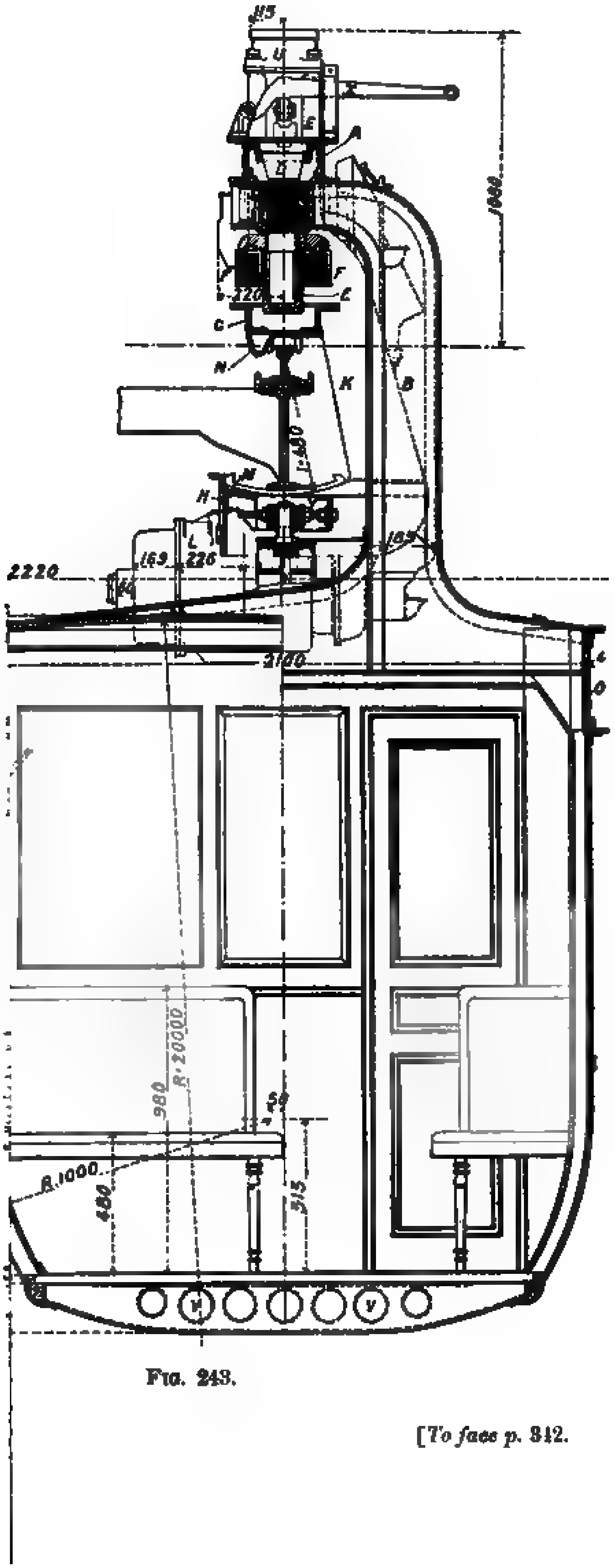


Fig. 243.

[To face p. 342.

clearance of $\frac{1}{4}$ inch, under the rail-carrying I-girder, and thus prevent any derailment by jumping of the wheels at rail joints and accidental obstructions. The wheels are double-flanged, the flanges being $1\frac{1}{4}$ inch deep. Thus if they jumped $\frac{1}{4}$ inch, which is the maximum allowed by this guard, there would still be a margin of 1-inch depth of wheel flange preventing derailment. This margin is diminished by the wear of the rail-head, this increasing the above $\frac{1}{4}$-inch clearance. But $\frac{3}{8}$-inch wear is more than would be allowed before renewal of the rails, and this wear would still leave a margin of $\frac{5}{8}$-inch flange depth as security against derailment. The middle girder G has two openings under the wheel axles, in which openings the two wheels lie. It carries the guard-rail N, which prevents lateral derailment in the event of breakage of a wheel or axle, when the girder G falls on the rail and slides on it, thus supporting the bogie and car in default of proper wheel support. The upper girder AA carries the axle-boxes of the two wheel axles, the air-brake cylinder U, and the collar-bearing E. The two vertical end-girders K, K carry, through short links, the two beam-plate springs F F.

The mono-rail supports the wheels; these through the axle-boxes carry the top girder AA; from this, through K, K, hang the springs F, F, and these springs carry at the middle of their length the vertical swivel-pin D, from which hangs the whole weight of the car body. The pin D is fixed fast in the top of the strong and very stiff cranked vertical girder bracket B, seen plainly in the section, the base of which spreads horizontally into a massive cross-girder stretching right over the roof of the car and riveted to the top longitudinal side beams of the car body.

From the drawing it will be seen that the swivel-pin D rests in a foot-step, E. The upper flange of this foot-step is extended in two strong side lugs, in the under surfaces of which are turned semi-globular bearings. These cup bearings rest on the globular heads of the centre shackles of the plate-springs F. This form of bearing gives the maximum possible freedom of elastic jointing between the springs and the pin D which they carry.

The pin D at its top end swivels in the collar-bearing E, which is externally a square block having a sliding fit inside the box-girder AA of the bogie frame. The pin D being fast in the bracket B and thus rigid with the car body, this top collar-bearing E keeps car body and bogie frame in vertical alignment at the top level of the latter. They are again kept in alignment at the level of the bottom bogie girder H by the pin X. This pin is fixed rigidly in the cross-girder base of the bracket B. It swivels in the block Y, which is of square outside shape. This block Y has a sliding fit between two short plate-springs, bolted to the girder H, and these springs allow it some lateral flexibility of position in the bogie frame. This is necessary, in order

to allow the two bearing springs F, F to deflect by slightly different amounts, which is essential to their free action and easy riding, but the springs at X Y prevent the vertical centre plane of the bogie deviating by more than a very small angle from that of the car body.

The vertical cranked bracket B is, of course, placed near the centre of the length of the bogie, and stands between the two running-wheels and between the two end brackets K, K of the bogie frame. The ends of its cross-girder base are strongly riveted to two steel girders O, O running along the top of the car body over the windows. These girders O, O are thus suspended each at two points of its length, namely, at the centres of the leading and rear bogies. To these girders are riveted ⊔ irons carrying the floor-sills of the car bodies. In fact, all parts of the car body are suspended from the top side-beams O, O. In the car, wood is used only for filling in; all the structural parts are of rolled steel and iron and cast iron.

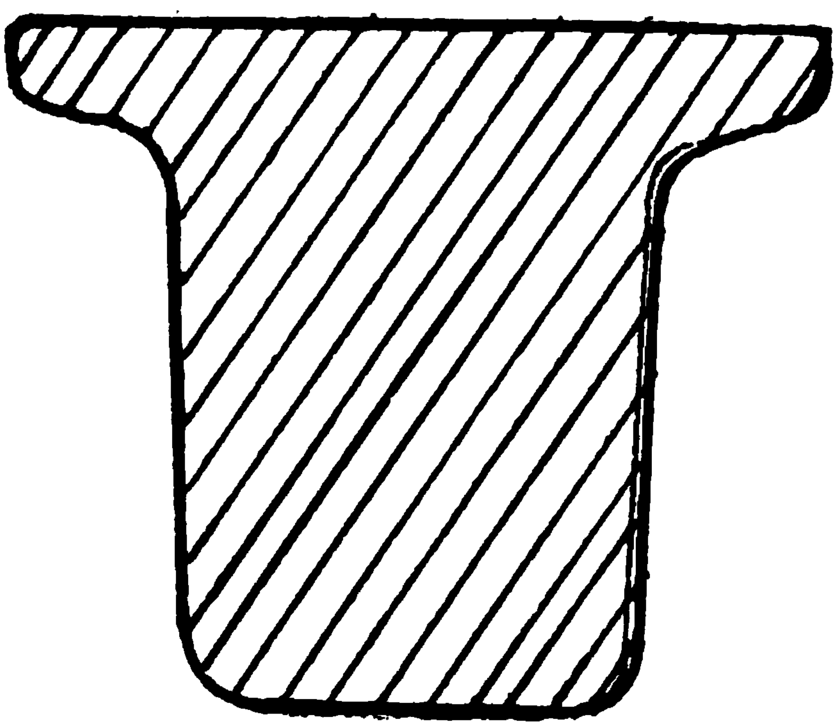


FIG. 245.—Section of new Conductor-rail.

There are three means of braking. The drawing shows quite clearly the linkage of the Westinghouse air brake, operated from the air cylinder U. There is one brake-block only on each wheel, acting on its top surface—the most efficient point of application for a single brake block. In the drawing the lever *a* indicates how this brake is operated by hand. The two levers *a* on the two bogies are connected so that both brakes are simultaneously applied by either the driver or the conductor. Both motors are also controlled so that electrical braking may be employed. The controller gives series-parallel regulation of the two motors of each car with the necessary rheostat starting resistances.

9. The current is taken from an overhead conductor-rail by a sliding contact. This rail is of steel of the section shown in Fig. 245. Its sectional area is 2·4 square inches, suitable for a steady current of about 400 ampères. It is hung under the floor of the track-girder, and the sliding-shoe is pressed upwards against it by springs acting on the base of a very short arm inclined only slightly from the horizontal.

10. The cars are 37½ feet long, 7 feet wide, and 8½ feet deep. The motor-cars are seated for 32 passengers, and weigh, empty, 12¼ tons. When crowded, 46 passengers are carried, and, so loaded, the

weight is about 16 tons. Each trailer-car weighs, empty, $11\frac{1}{4}$ tons, with 50 seats, and, when well filled, weighs about $15\frac{1}{4}$ tons. The motors are 4-pole of Schuckert pattern, of 36 rated horse-power, geared 4 to 1 to the driving-wheels, with 0·57 ohm armature resistance. There are two motors to each car, and generally two motor-cars to each train. The acceleration attained is over $2\frac{1}{2}$ feet per second-second, and $3\frac{1}{2}$ feet per second-second retardation is available with the full power of the brakes.

In busy parts of the day a $2\frac{1}{2}$-minute service each way is maintained, and the cars are well filled, being especially crowded on Sundays and holidays, when great numbers go to the Zoological Gardens at Vohwinkel, the western terminus of the line. The station stop is, by schedule, 15 seconds, and, as the trains are small and quickly emptied, this stop is not much exceeded. On the station platforms there are erected railings for the formation of queues, which prevent disorderly hustling in dismounting and mounting. The fares for the two classes are rated on the basis of $\frac{3}{8}$ and $\frac{9}{16}$ English penny per mile.

Including the terminal stations at Vohwinkel and Rittershausen, there are 20 stations, which makes the mean distance between them 0·45 mile, this spacing ranging from 0·69 to 0·19 mile. The worst gradients are 3 and 4 per 1000 in climbing to Vohwinkel. There are two curves of 75 and 85 metres radius, and fifteen curves of 90 metres radius, and the system shows very great flexibility as regards curves and gradients.

11. The current along the line is continuous at 600 volts, the drop from the power-house to the car varying from 50 to 150 volts. The current is sent out from the central station as direct-current at a maximum of 720 volts. This station, which is placed near the centre of the line, supplies light to the city of Elberfeld, and power to its tramways, as well as to the mono-rail. Its equipment includes 8 Cornish boilers, each of 1100 square feet heating surface, and two double Babcock and Wilcox water-tube boilers, each of 2500 square feet. The boiler pressure is 175 lbs. per square inch. There are two very fine Sulzer horizontal compound engines with quadruplex-seated drop valves, each of 1500 horse-power, and running 94 revolutions per minute. Each of these drives at one end of its shaft a 1000-kilowatt Brown-Boveri single-phase alternator at 4000 volts, with a 60 horse-power 100-volt exciter upon an extension of the shaft beyond the main bearing; while at the other end of its shaft it drives a direct-current Schuckert dynamo giving from 470 to 1420 ampères at voltage 600 to 720. It is from these dynamos that the mono-railway is mainly supplied.

The station also contains two Parsons-Brown-Boveri steam turbines, each direct-coupled to a 1250-kilowatt 4-pole alternator

delivering single-phase current at 4000 volts. The frequency is 60 per second. This part of the plant is only used at periods of full load. The peaks are carried over by a battery of 600 kilowatt-hour capacity.

12. A green-and-red-light block-signal system prevents a train leaving any station until the line up to the next station is clear. The passage of the trains automatically changes the signal. So long as a train is between any two contiguous stations, the signal-box behind the train shows a red light and bars the entrance of another train upon this section. When the train leaves the forward station, the red lamp at the hinder station is extinguished, while at the same time and place the switch to the green lamp is unlocked. But this last switch does not move, and the green lamp is not lighted, until the next train approaches this hinder station. The approach of this next train to within a hundred yards of the station switches current into the green lamp, provided the red lamp has been already extinguished, thus unlocking the green lamp switch. Formerly either the red or the green lamp remained always alight, but the novel system now mentioned, whereby neither is alight except when a train is on the section in front and except when a train is at a near distance behind, has saved 30 per cent. of current energy expended upon the working of the block system.

13. The stations are steel structures built upon extra strong arch-trusses of the same kind as already described, that at one end of the station being anchored, while that at the other end is supported from a pivoted truss, thus leaving the metal structure of the station freedom to expand. Ordinary metal staircases lead up to the platforms from the street pavements. The platforms are at the same level as the floors of the cars. It is to be noted that the Langen suspension design brings the platforms to a lower level above the streets than any other design of overhead railway for the same clear headway maintained in the streets.

An extremely interesting, and, indeed, unique, constructional feature in this road is the design of the loop whereby a westward going train may be transferred to the eastward line. This construction is found at the Vohwinkel, or east, end of the line, giving admission to the repair workshops there, and also at one intermediate station in Elberfeld. It is shown very clearly in Fig. 246. From this it is seen that the main eastward and westward rails run through without any break. On the left hand of the photograph the turn-out switch-point leading to the loop is shown closed, and a workshop repairing-car is shown approaching the closed junction from the loop. On the right hand the switch is thrown open. The switch "point" carrying the turn-out track-rail is, in reality, an extremely massive girder about 15 feet long and weighing over 1 ton. Its outer end is

FIG. 246. Turn out Switch on Elberfeld Mono-rail.

slung by a heavy double-pin hinge, which enables it to be swung horizontally through a large arc and also vertically through a very small arc. The small lifting motion is only necessary in order to take the weight off the closed joint and allow it to be unclamped easily. The point-girder is slung at mid-length, that is, near its centre of gravity, by a strong suspension link, the upper end of which is pinned to a small four-wheeled bogie running on an overhead turntable. This turntable carries a fixed spur-wheel, or segment. An electric motor drives the bogie along the turntable by a pinion gearing in this spurred segment. The mechanism works smoothly and accurately, and the author found that it could be opened and closed in 30 seconds. The "loop" passes underneath the two main lines.

14. The cost of the constructional part of this extremely interesting line was over £42,000 per mile along the river, and over £30,000 per mile along the high-road. Its electrical equipment cost £2400 per mile, exclusive of the above-described block system. The motor-coaches cost each £835, plus £615 for two motors and electrical equipment.

The cost would have been less but for the great variety in the lengths needed for the columns of the arches over the river and the great variety of their inclination, which prevented much standardization in the design and manufacture of these trusses.

CHAPTER XI

HIGH-TENSION ALTERNATING-CURRENT RAILWAYS IN ITALY

1. Ganz Railway at Lake Como—2. Differences between Urban and Main Line Railways—3. Physiography of the Line, Train Service and Traffic—4. Line Construction and Rolling-stock—5. The Ganz Cascade System—6. The Hydraulic Power-station—7. Turbines and Dynamos—8. The Switchboard—9. The High-tension Line—10. The Sub-stations and Transformers—11. The Trolley Line—12. Safety Appliances—13. The Trolley—14. The Motor-coaches and Motors—15. The Driving Linkage—16. The Locomotives—17. Automatic Electric Block System—18. Capital and Working Costs—19. New Express Passenger Locomotives—20. Comparison of High-tension Alternating-current and Low-tension Direct-current Railways—21. North Wales 3-phase Railway—22. Three-phase Railway in Canada: London to Port Stanley.

1. WHAT is probably the most interesting advance in electric traction the world has yet seen was completed in its first stage in September of 1902 in Northern Italy. This is the high-tension 3-phase railway, with cascade motors, initiated and executed by Messrs. Ganz and Co., of Buda-Pesth, Hungary.

2. Hitherto electric traction has been readily adopted where the conditions are evidently most favourable to its success. That is to say, it has been put in operation for the intense passenger traffic in and round about large cities. Along these routes there is to be served a constant stream of passengers; the individual cars or trains must be of comparatively small carrying capacity; they must pass each point of the route at very small time intervals; they must stop either indifferently at any and every point to let down and take up casual passengers, or else at stations only a small distance apart. Moreover, all the trains are local, stopping at all stations and following each other at the same speed; there are no express trains to overtake and pass the slow trains. For such traffic, absence of smoke and other dirt is willingly paid for at an extra high price, or, if this price be not demanded, this advantage attracts and increases the traffic. Finally, there is little or no goods traffic on such lines. On such lines the horse-power needed for each car or train is small; the

demand for horse-power is well distributed along the line; and this demand is also well distributed in point of time, so that the maximum does not bear any very excessive ratio to the average. In particular, the very heavy demand for current for starting a car or train causes comparatively small peaks, or sudden leaps, on the

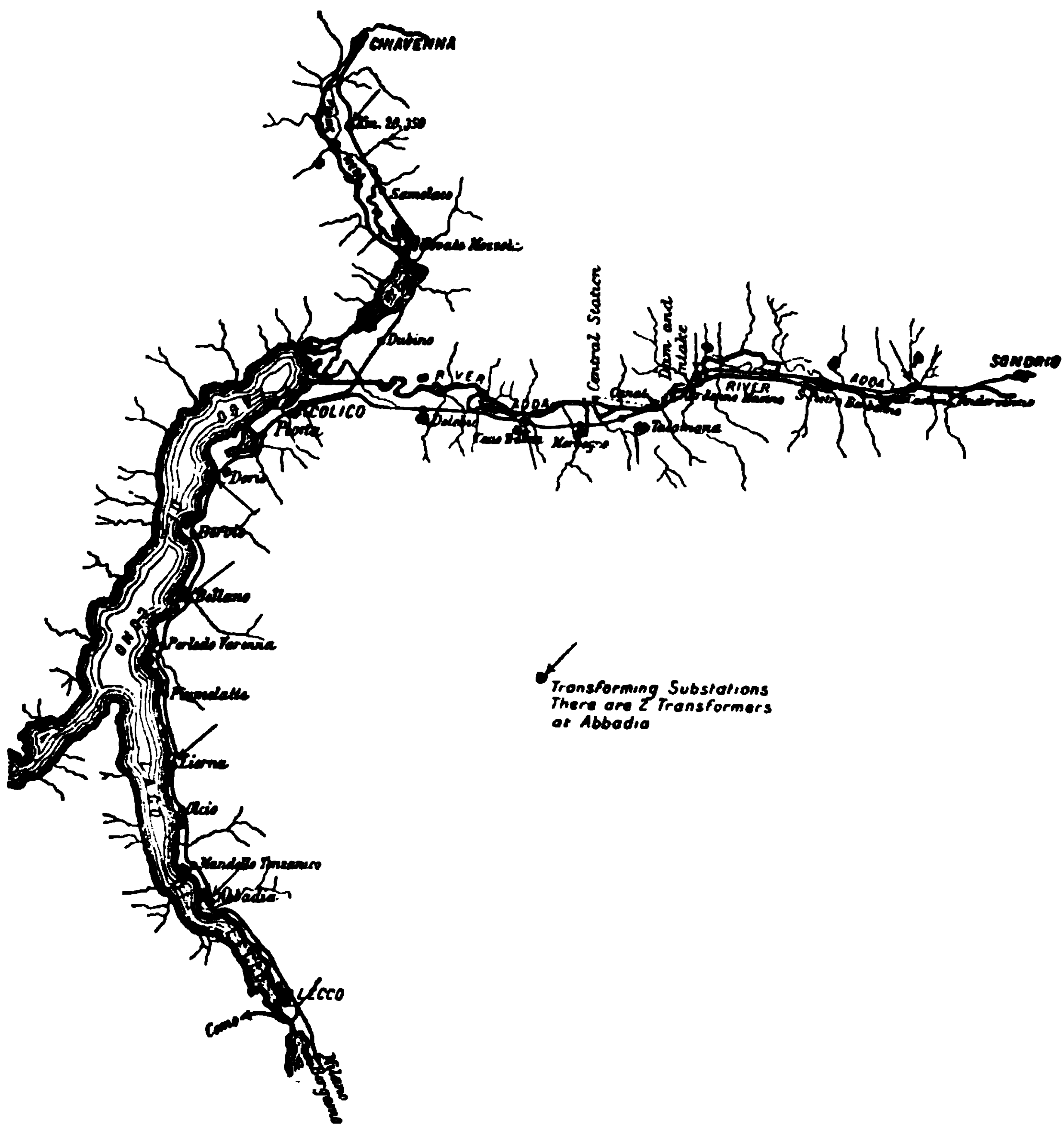


FIG. 247.—Route of Valtellina High-tension 3-phase Railway.

diagram of total consumption, partly because of the small weight to be started into motion, partly because the total current taken by the large number of running cars simultaneously with the starting of the individual car is great enough to render the excessive momentary consumption of this individual of no dominating importance.

All these conditions are most favourable to the application of electric driving power. But none of them obtain in *general* railway traffic. The problem of electrification of *general main* railway work is thus immensely more difficult. It is this problem that has been attacked by Messrs. Ganz and Co., in alliance with the "Adriatic Railway Co.," and the State Railway Department of the Italian Government, at Lake Como and Valtellina. These 67 miles of electralization have been executed as a demonstration to test the practicability and desirability of electric conversion of the whole of the network of railways right through the north of Italy. This being the purpose, an area was selected for the experiment which combined in an exceptionally high degree all the difficulties and disabilities of general railway traffic.

3. The railway through this area forms on the map a three-branch star, the junction being at Colico, at the north end of Lake Como. As seen on the plan, Fig. 247, one branch runs south, a length of 24½ miles, to Lecco, the centre of the silk manufacturing industry of North Italy, at the foot of the south-eastern arm of the lake. A second branch runs eastwards, 25½ miles up the Valtellina, to Sondrio; while the third, 17 miles long, leads north to Chiavenna. Sondrio and Chiavenna are exits from favourite tourist routes across the high alpine mountains, so that all through the summer the passenger traffic along the lines of this electric railway is heavy. The total length is thus 67 miles. Figs. 248, 249, and 250 give the profiles of these three branches, the distances, gradients, and curves being noted at the foot of each diagram. Between Lecco and Colico the lake shore is mostly rocky and precipitous, necessitating a tortuous course, half the length being in curves, and 35 per cent. of it in tunnels. A large proportion of the curves are of 1000-feet radius. There are frequent rises and falls, many of the gradients being 9 and 10 per 1000. Between Colico and Sondrio, in the middle half of the stretch, there is also much curvature and long grades of from 13 to 17 per 1000. In the northern branch to Chiavenna, the last 3¾ miles is steep, being mostly about 20 per 1000 gradient, while on one 1000-feet length the grade is 22 per 1000 and is coincident with a curve of 1000 feet radius.

The tunnels between Lecco and Colico are small in size, namely, 11 feet 7 inches wide by 18 feet 4 inches from rail-level to crown of arch.

We have here numerous tunnels, fairly sharp curvature, frequent gradients—all the physical difficulties occurring in railway work. The stations also are far apart, the average distance being 3 miles, while that between the stopping places of express trains is 8½ miles. Fig. 251 is a graphic time-table of the train service, which shows that, instead of small time intervals, the trains run at an average of

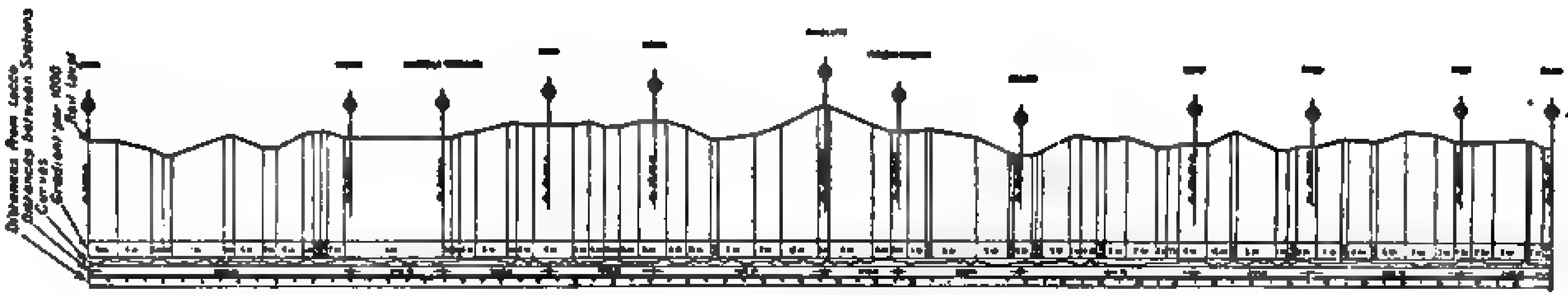


Fig. 248.—Profile of Line between Lecco and Colico.

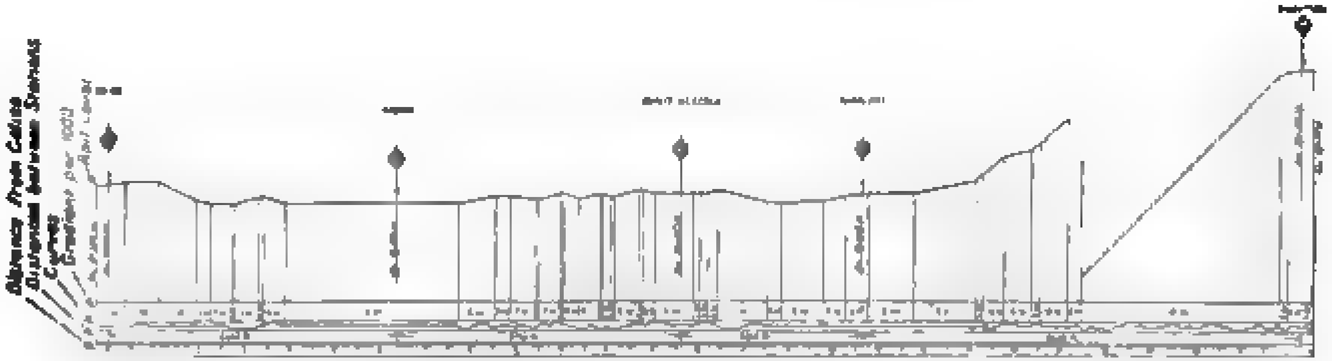


Fig. 249.—Profile of Line between Colico and Chiavenna.

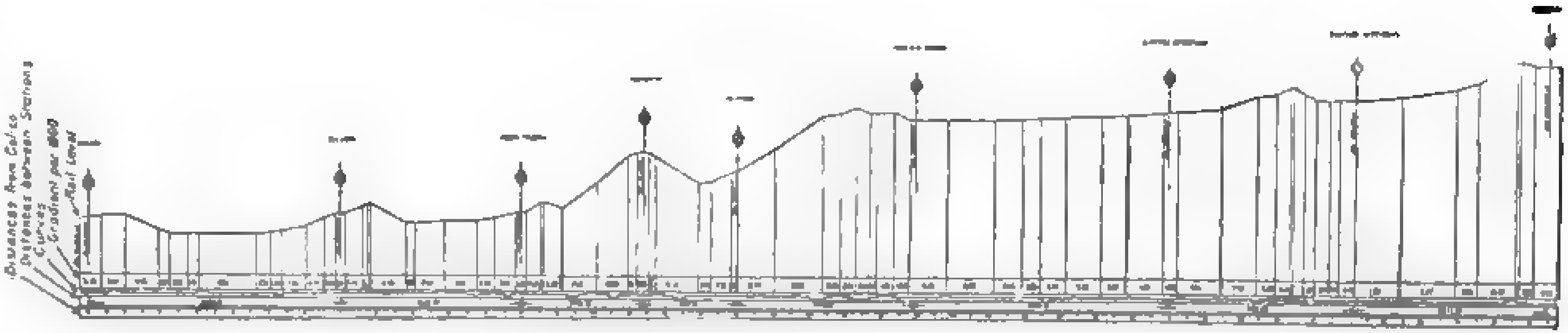


Fig. 250.—Profile of Line between Colico and Sondrio.

1 hour 40 minutes apart; that is, the traffic is the reverse of intense. The shortest interval between the departures from Lecco is 14 minutes; the shortest between arrivals is 11 minutes. Again, the passenger traffic is "mixed;" that is, the trains are partly local and partly express. On Fig. 251 the heavy lines indicate express, and light lines local, trains.

Furthermore, the goods traffic is as heavy as the passenger traffic. The goods trains are omitted from Fig. 251. The resident population served by these 67 miles is sparse; it is only 200,000 in the whole province, while only 54,000 live within a mile of the railway. The towns are little more than villages, the largest, Lecco and Sondrio, having each between 8000 and 9000 inhabitants, and Morbegno, Colico, and Chiavenna only between 4000 and 5000.

The traffic receipts, gathered half from passenger and half from

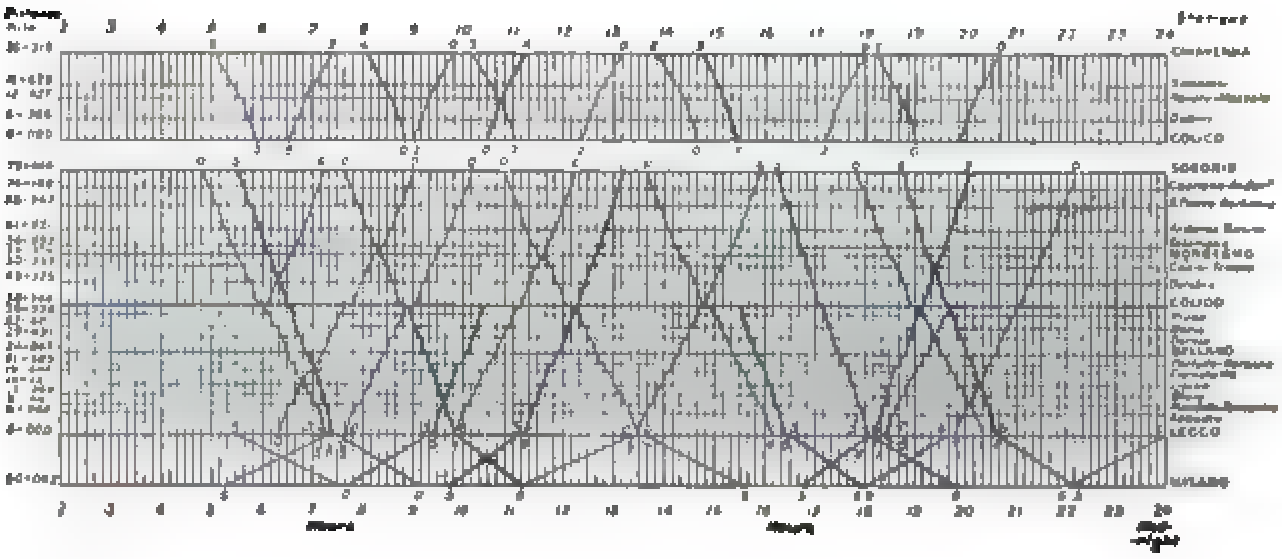


FIG. 251.—Graphic Time-table.

goods traffic, amount to only £600 per mile, and 3*s*. 4*d*. per train mile. The average over the whole of the Adriatic Railway Company's lines was £1450 per mile, of which £630 was from passenger traffic. This £1450 means 5*s*. 9*d*. per train mile, or a traffic nearly twice as productive as that on the Valtellina branches chosen for the trial of electric traction. On this latter the average fare paid per passenger is about 1*s*., while over all the companies' lines it averages 1*s*. 10½*d*. Thus the trial of the efficiency and economy for the new traction is being carried out under the severest and most unfavourable conditions. English railways are greatly more productive per mile of track than the figures above mentioned. In England and Wales the traffic receipts in 1900 were £6000 per mile, and in the British Isles £5000 per mile, and they are increasing at the rate of 3½ per cent. per year. As against the above 5*s*. 9*d*. receipts, the

average working costs in North Italy are 4*s.* 3*d.* per train mile, and of this 7¼*d.* is spent in fuel.

The results have been so far satisfactory that the Minister of Public Works has expressed his personal approval to the 31-mile extension of the electrification southwards from Lecco to Milan, by way of Monza. The traffic on this extension, and especially between Monza and Milan, is very much heavier than any north of Lecco. The central power station has been laid out so as to be able to supply energy for this extension. Another extension, 26 miles long, proposed to be served from the same power station, stretches across

FIG. 252.—Valtellina 3-phase Motor-coach.

country over high ground between Lecco and the town of Como, at the south-western end of the lake. When these additional lengths come into the network, the capital outlay upon the power station will be reduced to due proportion to the work to be done. At present only a small fraction of its power capacity is being utilized.

4. The lines north of Lecco are single track throughout, 4 feet 8½ inches gauge, with steel Vignole rails, weighing 55 lbs. per yard on the Chiavenna-Colico-Sondrio branches, and 71 lbs. between Colico and Lecco. Reference to Fig. 251 shows that the express speed, inclusive of stoppages, is 26 miles per hour, while that of the local trains stopping at all stations is 20 miles per hour. Between stations

it rises to above 40 miles per hour. There are in all twenty-four stations in the 67 miles, at nine of which the express trains stop. The average distance apart of the express stations is thus 8½ miles, while that of local stations is nearly 3 miles.

The trains on the electric line are made up of the old rolling-stock plus the new motor-cars and the new goods locomotives. A motor-coach is shown in outside view in Fig. 252. Fig. 253 is a similar view of a goods locomotive. The motor-coaches each weigh 53 tons. A train of five coaches weighs about 100 tons. The motor-coach is 64 feet long over buffers, and its roof stands 13 feet 4 inches above the rails. The trolley-wires are 20 feet above the rails in the open and 16 feet in the tunnels. Half of the coaches have first-class drawing-room and smoking saloons, seated for forty passengers; and the other half have second and third-class compartments, the two together giving fifty-six seats. They are entered from the ends, where also are placed the drivers' cabins, with closed-in roof and glass front. Each motor-coach has a small baggage compartment. The goods locomotive weighs 46 tons. It is capable of starting a 270-ton load on an up gradient of 11 in 1000, or of drawing 450 tons at 18 miles per hour uniform speed on same grade. The four motors in each locomotive are separately controlled and are not in cascâde, their total maximum horse-power being 600. The four motors in each motor-coach are in two cascade pairs, and at half-speed they together can exert 300 horse-power. Other locomotives have also been put on the line to draw express passenger trains of 250 tons at speeds up to 44 miles per hour on 10 per 1000 gradients, and goods trains of 400 tons weight at speeds up to 22 miles per hour on the same grades.

5. The Ganz system consists in bringing the energy from the central generating station along the line as 3-phase current at 20,000 volts and 15 per second frequency; transforming this at sub-stations without rotary converters to 3000-volt 3-phase current, also, of course, at 15 frequency, which is collected from the trolley-wires and led direct, without other conversion, to motors driving, without gearing, the wheel-axles. The motors are pure induction 3-phase motors. They are arranged in pairs, high and low tension. The arrangement is not correctly comparable to that of a compound steam-engine, and therefore the name "Cascade" has been invented to describe, or rather to identify, it. Each motor consists of a higher-tension stator and lower-tension rotor. The 3000-volt current from the trolleys enters the stator of the high-tension motor, and excites a magnetic field which rotates at a speed proportionate to the frequency. This induces in the rotor of this motor a 3-phase current, whose voltage does not rise much above 300. The periodicity of this current through the rotor is a maximum when the rotor is

stationary, and diminishes towards zero as the rotor speed rises towards synchronism with that of the rotating magnetic field. As the difference of speed between the two decreases, so also does the E.M.F. induced in the rotor windings, and, therefore, also, other things being equal, the current generated by this E.M.F. The decrease of the current may be, however, wholly or partially neutralized by gradual cutting out of resistance inserted in the rotor circuit—the currents through the three windings of the rotor being led off by three slip-rings—or by cutting out of counter E.M.F. inserted in this same circuit. This rotor current is, during starting and accelerating up to "half" speed, and also during retardation from full to half speed, led into the stator of the low-tension motor. Here it meets with counter E.M.F. from the inductive action between stator and rotor, *i.e.* between primary and secondary, of this second motor. During this time no rheostat resistance is inserted in the circuit of this first induced current; but the 3-phase current induced in the rotor of the second motor is taken through a non-inductive liquid-resistance rheostat. This rheostat automatically reduces, at a speed controlled by the greater or less opening of an air-valve, the resistance from a maximum at starting to zero when "half" speed is reached, this being the synchronous speed for the low-tension machine. The low-tension motor is now cut out of circuit and runs idle during acceleration from half to full speed; while at the same time the full rheostat resistance is switched into the direct circuit of the rotor current of the high-tension motor, being once more automatically reduced from maximum to zero while the speed is rising from "half" to "full." "Full" is the synchronous speed for this motor working alone.

In slowing down, this series of operations is reversed. In slowing from full to half speed, the two motors are coupled in cascade. They then act as dynamos generating instead of absorbing current, and returning energy to the trolley-line in the shape of 3000-volt 3-phase current, which is utilized elsewhere in driving other trains. The train is thus braked electrically from full to half speed. This is the means of recovering in useful form the greater part of the kinetic energy in the train at its maximum velocity. Except for C^2R and hysteresis and frictional losses, three-quarters of the kinetic energy would be so recovered during retardation to half speed. In slowing below half speed, the second motor is again cut out and runs idle, while such braking as may be needed is done by Westinghouse air-brake blocks on the wheel tyres. Only one-quarter of the kinetic energy has to be dealt with in this way.

The most striking advantages are low prime cost and low working costs in the transforming sub-stations, saving of copper in the trolley-lines, and higher load-factor (or levelling of variation of demand for

energy) in the stations, because of the high trolley tension distributing the supply over longer lengths of track.

6. The power is obtained from turbines driven by water from the river Adda, brought from a point near the Bridge of Desco, between Sondrio and Morbegno, by a canal 3 miles long, which follows the valley, running along its higher northern slopes. At Desco advantage was taken of a large gravel island in the bed of the river, which had been proved to afford a permanent solid foundation. A dam blocking up entirely the southern branch of the river, and sweeping diagonally across its northern branch, was built, sunk in

FIG. 253.—Valtellina 3-phase Locomotive.

the gravel and not rising more than a few inches above normal high-water level. At the end of this dam three great gates, each of $18\frac{1}{2}$ feet span, and permitting a maximum depth of $7\frac{1}{2}$ feet of water to pass them, give passage to the surplus water into the lower reach of the natural bed of the river. The gates are iron structures, and are raised and lowered by overhead cranes, according to whether the river is in flood or at low level, so that the extreme variation of level in the power canal is $2\frac{1}{2}$ metre to 2 metres depth of water, and gives never less than $\frac{6}{10}$ metres depth over the sill of the intake. The intake to the power canal is at right angles to these gates and parallel

to the natural bed. It is 34 metres long, and is protected by a grid of flat iron bars inclined 30 degrees from the vertical, and with the flat faces of the bars set with a horizontal inclination such as tends to prevent the inflow of ice and *débris* and to throw it off down stream. From the intake the canal starts immediately in tunnel and in a quadrantal curve of 35 metres radius. This tunnel is almost half a mile long, and is, for the most part, through solid rock, the mountain side being here, and throughout most of the length of the canal, steep and rugged. In the 3 miles of canal there are no less than fourteen tunnels, whose combined length is just 2 miles. The canal section has a uniform floor width of 4 metres and 4·4 metres at water level, with concreted floor and walls. In tunnels the roof is arched to a circular arc of 2·92 metres radius. Various constructions occur along the length, according to whether the cut is in tunnel, in the open, or in cut-and-cover, and whether it is in rock, earth, or partly earth and partly rock. At the issue from the long tunnel, an overflow into the bed of the river is provided, which steadies the canal flow below this point. Near the power-house another overflow of larger size is built, capable of taking the total flow.

The gathering ground of the Adda above the intake has an area of about 1000 square miles, and gives a minimum winter flow in the river of about 25 cubic metres, or 880 cubic feet per second. The total fall from the intake down to the highest level in the turbine tail-race is 32·6 metres, of which 4·8 metres are spent on the canal gradient of 1 per 1000 throughout 4·8 kilometres length, and another ½ metre is otherwise lost. This leaves 27·3 metres available fall from the top-level in the flume to the tail-race; which, with 25 cubic metres flow, gives $\frac{1000 \times 25 \times 27{\cdot}3}{75} = 9100$ theoretical water horse-power. It is reckoned that over 7000 horse-power will be developed by the turbines from this water consumption. Each of the three turbines now installed is designed for 1500 horse-power normal, with a 2000 horse-power overload capacity, while the fourth, still to be laid down, is of double this size. The four together will thus be of 7500 normal, and 10,000 maximum horse-power. It must be remembered that the above 25 cubic metres is the minimum winter water-flow, the summer flow being much greater, while the summer railway passenger traffic is at least twice as heavy as that to be served in the winter.

The canal ends in a rock tunnel in which is formed the settling basin of the penstock, 24 feet wide, 87 feet long, with a sloping floor, giving 21 feet depth at its forward end, where sludge and *débris* are collected, and discharging over a sill, surmounted by an iron grating, with 10½ feet of water over it. From here the water enters two steel flume tubes of 8½ feet inside diameter. These run straight down the

hillside at 45 degrees inclination to the horizontal. They are 234 feet long, and pass under the high-road, rising again in the station-house to the inlet casings of the turbines, each tube branching in two and supplying two turbines. Near their upper ends, where the water pressure is light, these tubes have packed gland expansion joints. Their upper ends are flanged and riveted to an iron plate built into the masonry of the penstock, the under sides of the tubes being open for inspection right up to this flange-joint.

The power-house is a spacious building 170 feet long by 72 feet wide and 50 feet high. Each turbine discharges by its own independent draft tube, whose mouth is kept well below the lowest water-level in the tail-race. This latter is a wide, open basin delivering

FIG. 254.—Valtellina Hydraulic-Electric Power-house.

directly into the bed of the river Adda a short distance above the Bridge of Ganda.

Fig. 254 is a photographic view which shows well the gallery of the overflow, the building over the penstock, the two great steel flume-tubes, the power-house, and the tail-race basin.

7. Fig. 255 is a general view of a coupled turbine and dynamo. Figs. 256 and 257 are plan and side elevation of this turbine and dynamo.

There are four turbines and two flume-tubes. The turbines are right and left handed, and arranged in pairs, one flume delivering to each pair.

The turbine and alternator are on one horizontal shaft, carried on two main bearings only, with the alternator between them and the turbine wheel overhanging the further bearing. The end of the

turbine shaft is, of course, steadied in the stuffing-box of the turbine casing, but this takes no bearing load. Further, the turbine shaft is prolonged in a small size extension to the governor housing, where it drives the governor and has a small extra bearing; but this again takes none of the weight of the wheel nor any of the working forces. In regard to this overhang, however, it must be remembered that the working pressures of the water are nearly uniformly distributed round the crown of rotating blades, and, therefore, have zero, or only a small, single resultant productive of pressure at the bearings. Their resultant is a torque or couple of equal and opposite forces. Practically the same may be said of the mechanical forces between the armature and field of the alternator. So that the main bearing pressures are really due only to the dead weight of the revolving parts and of the water filling, at any one instant, the crown wheel. What other pressure has to be taken up by the bearings is caused by the want of that symmetry and uniform circular distribution of the working forces which is intended and which ought theoretically to be complete and perfect. The two main bearings have a combined length of 8 feet 2 inches, and a diameter of 12 inches. Each is lubricated by three loose rings dipping into the oil chamber, and has a cooling-water circulation through the shell of the plummer block.

The turbine is inward flow, discharging the water horizontally parallel to the shaft, and the slightly expanding draft tube is immediately turned downwards. It dips 6½ metres, or 22 feet, below the turbine centre to some 18 inches below the lowest water-level in the tail-race. The diameter over the tips of the blades of the wheel is 5 feet 3 inches, and the normal speed is 150 revolutions per minute. A vertical-spindle ball-governor controls the entrance of water to the turbine. A relay pump pumps oil into an ordinary hydraulic accumulator, the pump being driven by an overhung crank on the extension of the turbine shaft. The oil pressure is maintained at six atmospheres, the flow from the pump escaping by a bye-pass into a reservoir when the accumulator is full, whence it passes again to the suction of the pump. From the accumulator the oil is supplied to one or other end of the horizontal relay cylinder whose piston and piston-rod thrust forwards or backwards, through a small angle, the ring commanding the crown of pivoted entrance guide-blades which admit water to the wheel. Such a cylinder and piston, constituting a relay regulating engine, is called a "servomotor." The centrifugal governor regulates the admission of pressure-oil to one or other end of the servomotor by means of a slide valve. There is also hand-wheel control of this crown of guide-blades, as well as a screw gear for opening and closing the main butterfly water valve, seen in Fig. 257.

The exciter dynamo is mounted direct on the other end of the main shaft, with a small outside bearing. The fields of the three

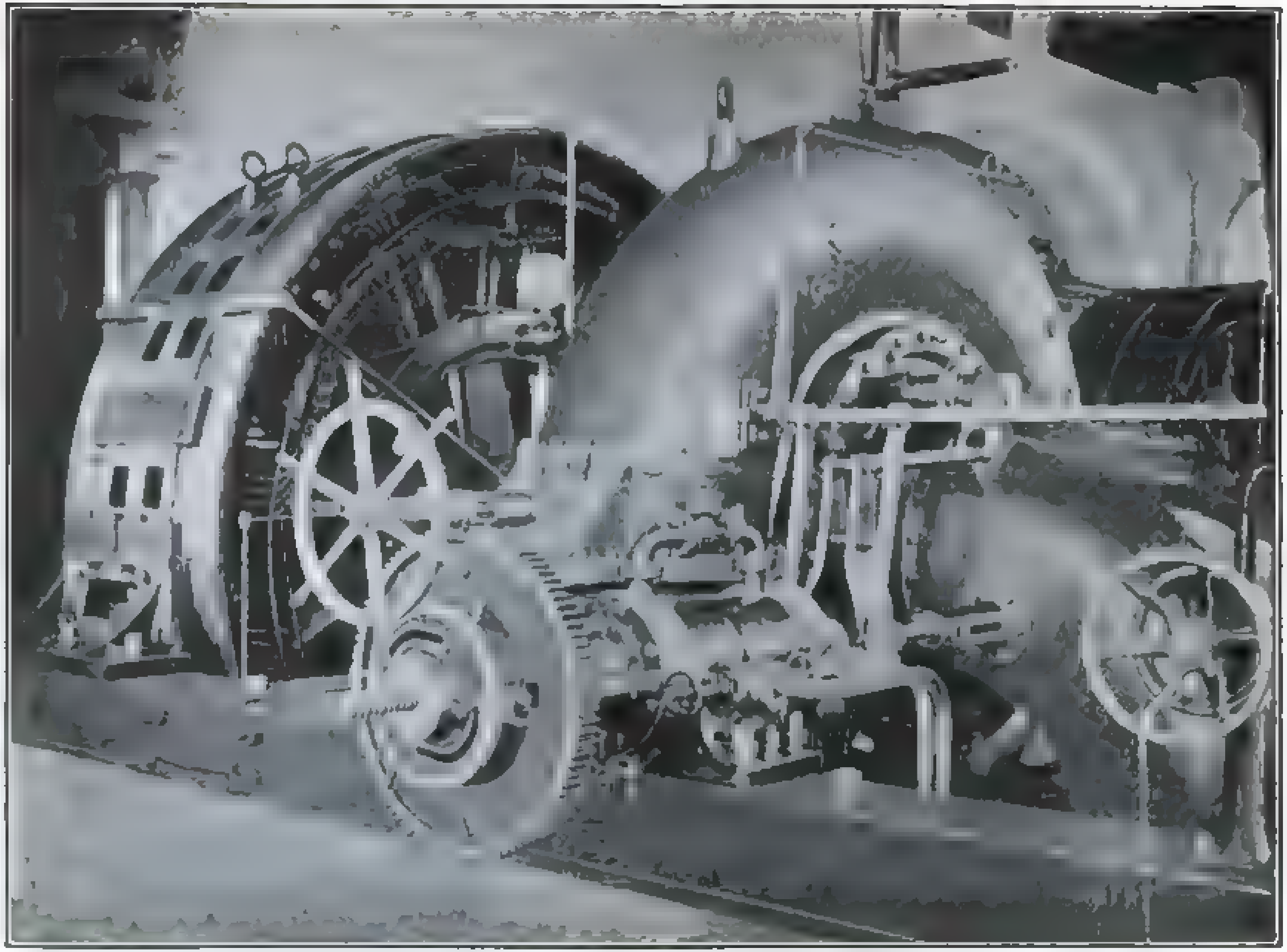


FIG. 255.—Ganz Hydraulic Turbine and 20,000-volt 3-phase Alternator.

exciters are excited by a small auxiliary dynamo driven by a small auxiliary turbine, which latter is also used for other donkey work. A rheostat is inserted in the exciting circuit, whereby the field of the alternator may be regulated from the switch-board. Furthermore, a small horizontal-spindle centrifugal-ball governor inserts an extra resistance in the field of the exciter dynamo if the velocity

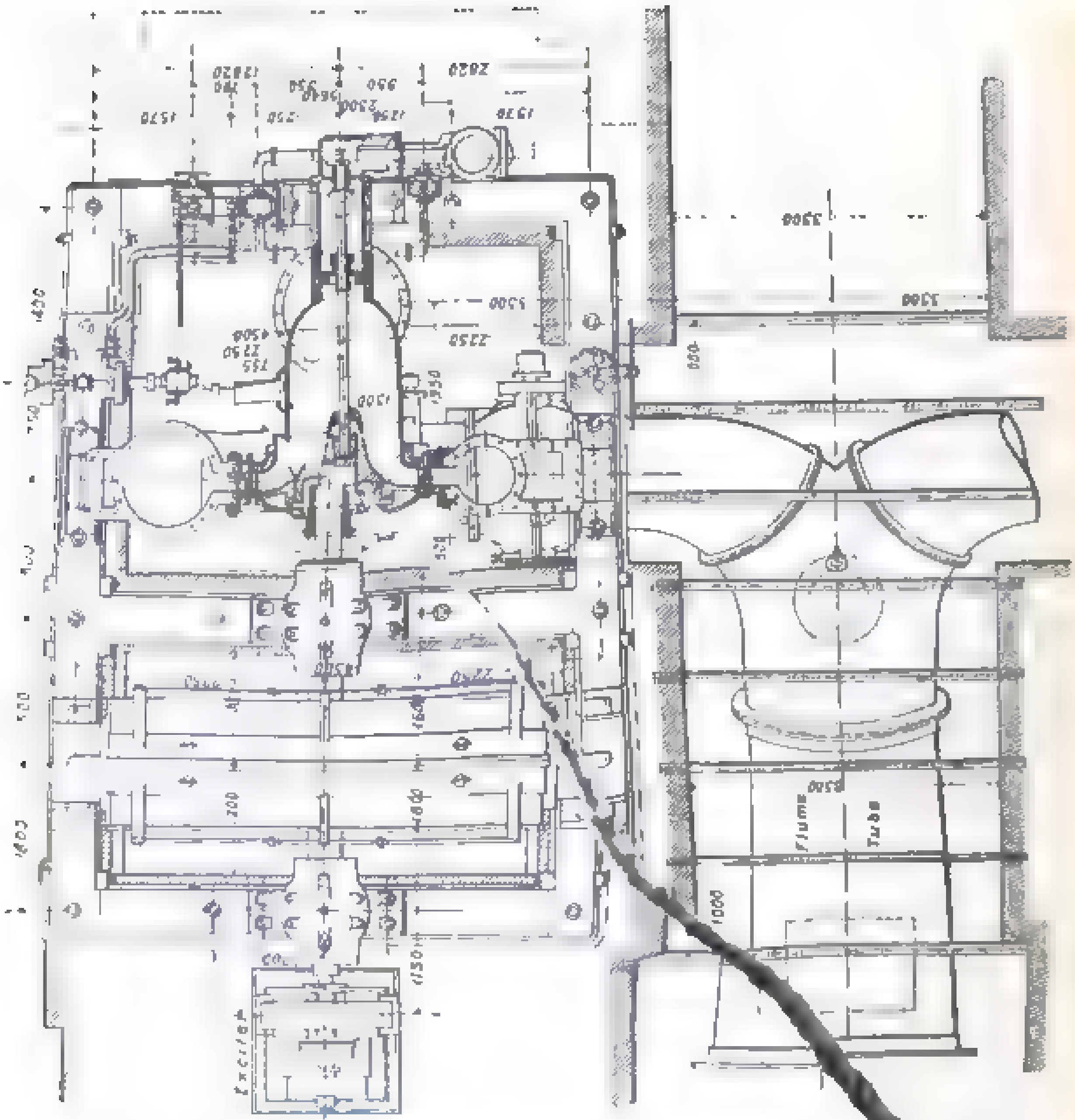


Fig. 25[illegible]. — Plan of Turbine and Generator.

passes beyond the limit of 270 revolutions per minute, at which the voltage of the alternator would have become 27,000. The alternators are, however, capable of running for half an hour at 30,000 volts without becoming heated to such an extent as to incur injury. The exciter voltage is 49·50 and the exciting current varies from 300 to 450 ampères averaging 370. The main current is 3 phase, of frequency 15 per second, the number of poles in the field being 12.

The normal voltage of the alternators is 20,000, and it varies between 17,000 and 22,000. A short circuit produces a current six times the normal, and this can be borne during about two minutes without doing damage. In normal work the coils do not heat above 45 degrees Cent. over atmospheric temperature. In putting on full load from no load the decrease of voltage does not exceed 15 per

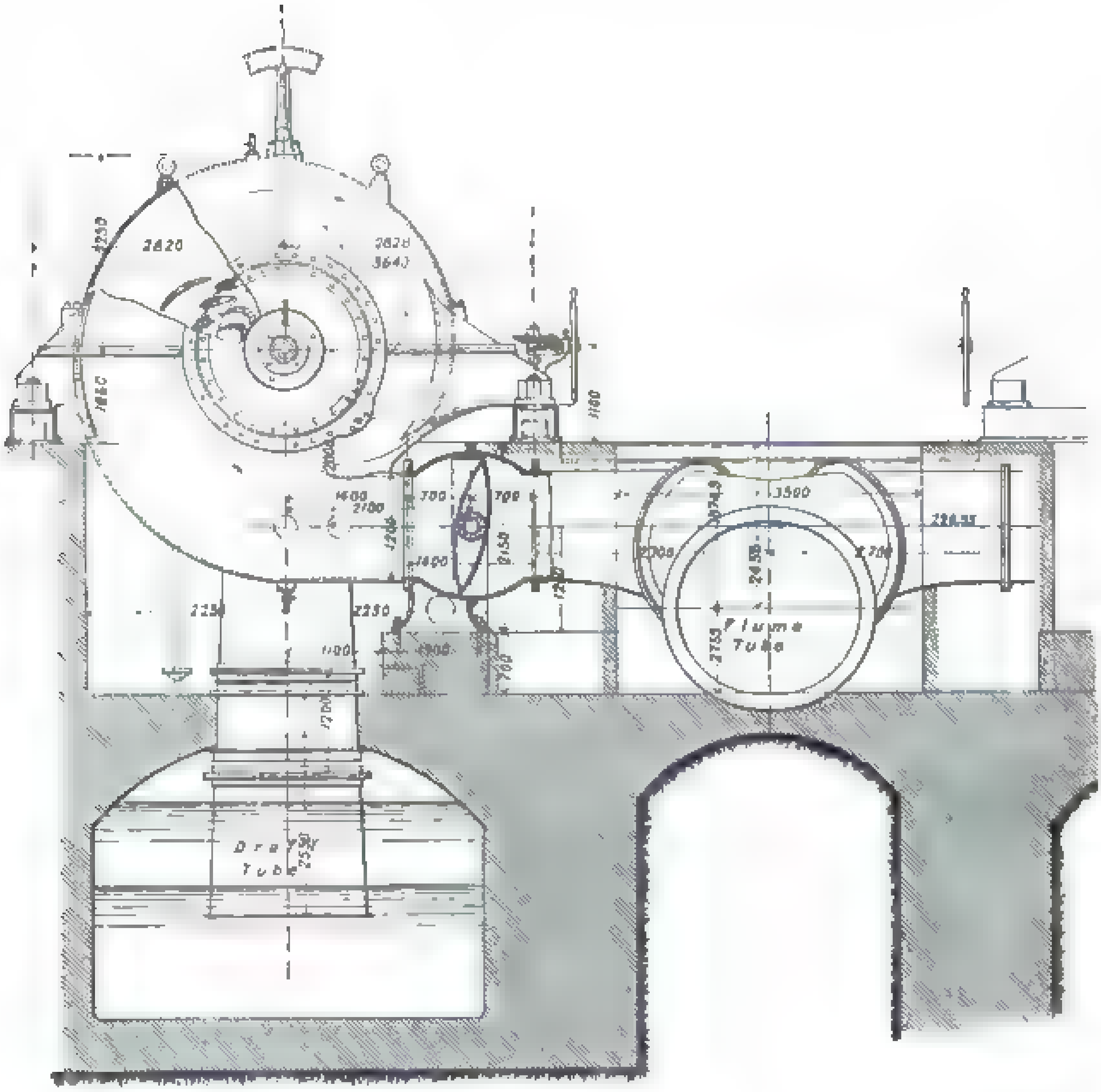


Fig. 257.—Side Elevation of Turbine.

cent., and on passing suddenly from full to no load it increases 10 per cent.

The alternator has an external diameter of about 16½ feet, and weighs 70 tons, of which 44 tons are in the rotating field. The wire of the field winding has 450 square millimetres section, or one square millimetre per ampère of maximum exciting current. The fixed external armature has eight teeth per pole. Two out of the eight

grooves, however, contain no windings. The coils are insulated in micanite tubes 6 millimetres thick. Their wire has $4\frac{1}{2}$ square millimetres copper section, and is cotton-covered. When an alternator is thrown out of work its field circuit is broken, the absence of current in the field of the exciter being insufficient to wholly prevent some excitation in the main field of the alternator.

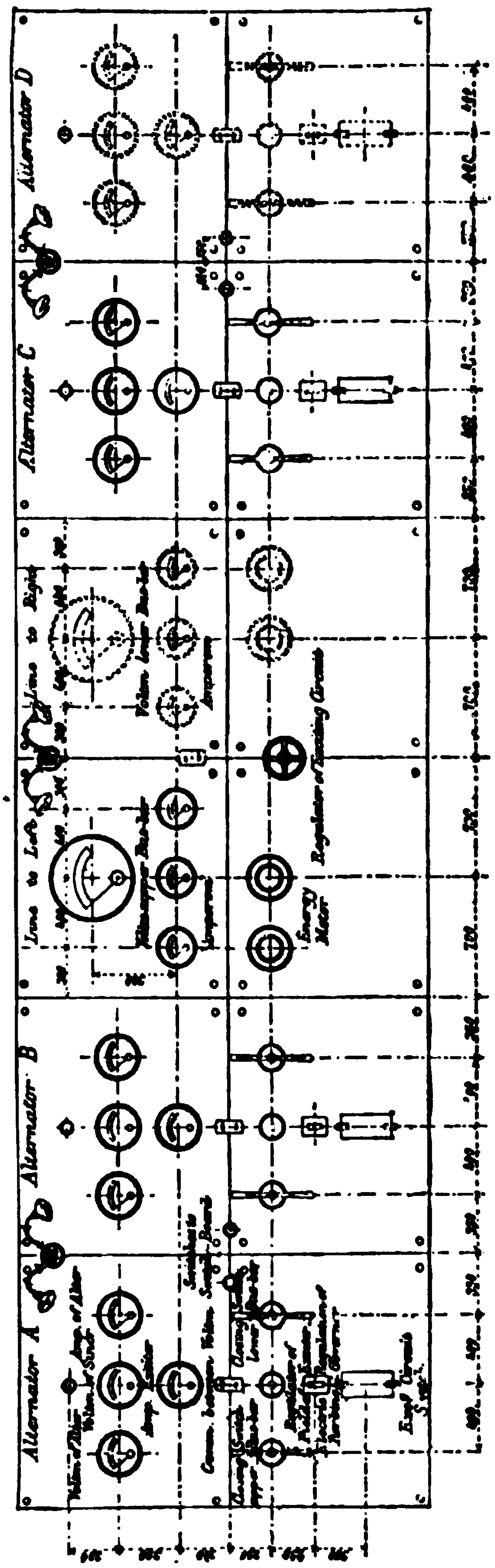


FIG. 258.—Main Switchboard, Morbegno Power-house.

8. The current is led off to two sets, "upper" and "lower," of three bus-bars each, being taken, well insulated, under the floor of the main dynamo hall to the large switch and safety fuse hall behind the switchboards. There are six vertical marble panels in the switchboards, as shown in Fig. 258. All the measuring instruments upon the switchboard are at low tension, being operated through small transformers.

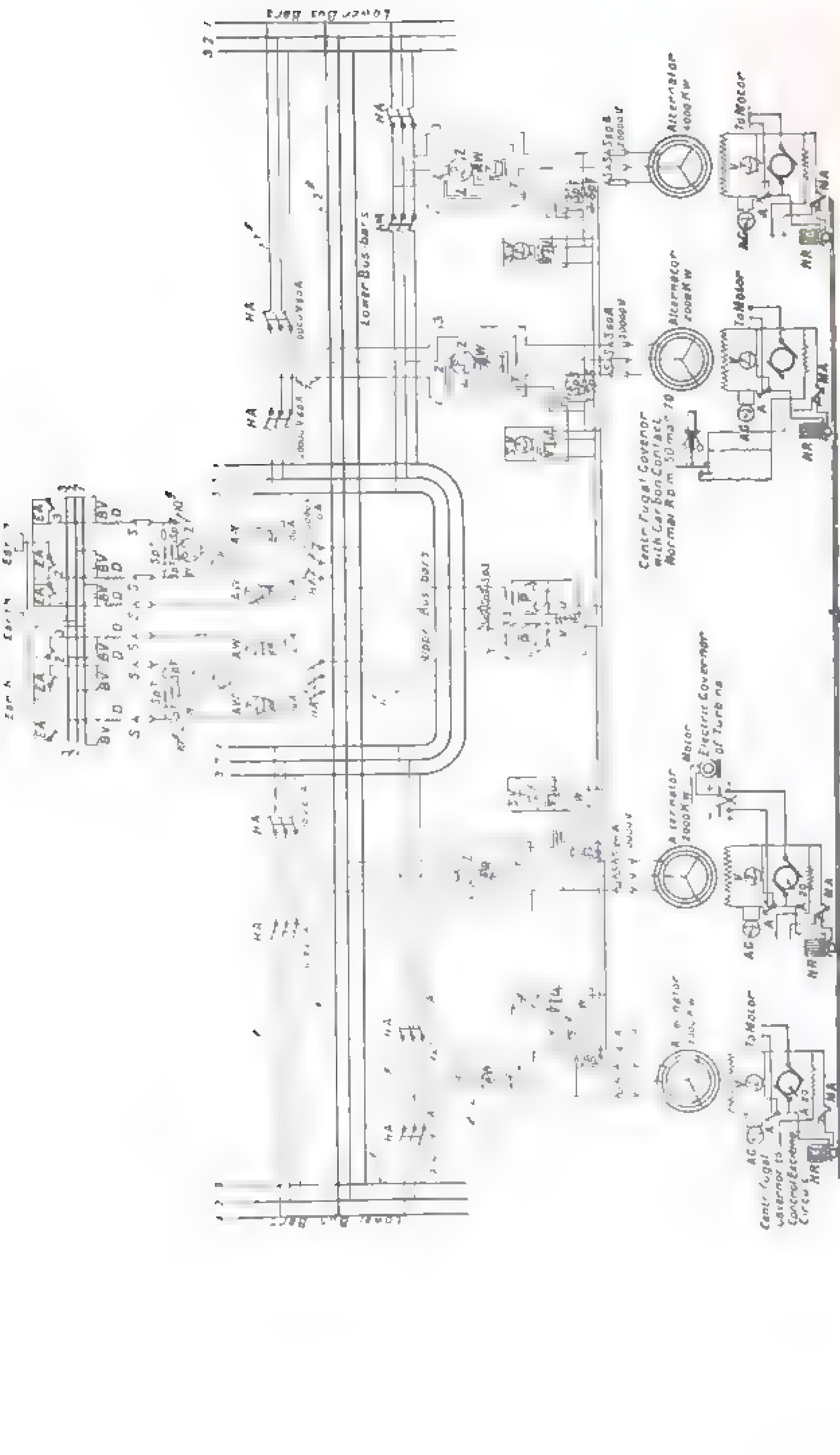
Fig. 259 is a schematic diagram of the connections. Of the six panels the two centre ones correspond to the upper portion of the diagram Fig. 259, and serve the two sets of external lines, or bus-bars.

The four other panels serve the four alternators. The explanatory notes upon Fig. 259 will make the arrangement clear to the reader. For each set of bus-bars there are three ampère meters, a voltmeter, and an energy meter. For each machine there are an ampère meter, a voltmeter, and a synchronizing voltmeter, as well as an ampère meter for the exciter. In the exciting circuit there is a regulating rheostat and a cut-out switch. Each alternator requires two 3-pole

switches for connecting to either set of bus-bars. One 3-pole switch is seen on each bus bar-panel. All these switches are operated from the front of the board; but the switches themselves are placed some 20 feet from the ground in the hall behind it, and the gear by which motion is given to them is an endless rope stretched over two pulleys far apart. The safety appliances are generally of the same sort as for the transforming stations described below. Each safety fuse stands upright by itself in a chamber of three vertical walls and a floor of marble, and is inserted in a thick porcelain tube with a thick outer wrapping of paper. The lightning protectors are isolated by a brick wall from the rest of the installation. The "earth" is a stout copper plate some 6 feet square placed in good electric contact with the water of the tail-race of the turbines.

9. The railway current is taken from the bus-bars of the generating station by three bare copper wires of 8 millimetres diameter across the river and the fields to Morbegno station, and thence up and down along the line to the transformer sub-stations. They are carried on larch poles of not less than 10 inches diameter at top and 12 inches at base, whose butt ends are burned and tarred. Along the railroad these same posts carry the 3000-volt contact wires. Halfway up each post there is an iron circlet or band whose lower and upper edges are cut and bent into rings of protruding spikes. These are intended to prevent boys from climbing the posts. The insulators used are shown in Fig. 260. They are five-lipped, and are tested at 60,000 volts. They stand on 8-inch brackets on the outside of the post, with 2-feet vertical spacing between the three wires. The section that runs up the valley from Morbegno is of 7 millimetres diameter wire. From Morbegno to Colico 8 millimetres is used, and from Colico in either direction towards Chiavenna and Lecco again 7 millimetres. Reference to the map (Fig. 247) will show that there are nine transforming stations. The last station up the valley is 3½ miles short of Sondrio, and there are three lying between Colico and Sondrio, averaging 7½ miles apart. There is one only on the Chiavenna branch, and this one lies 13 miles north of Colico. Towards Lecco the primary does not go beyond Abbadia, which is 4½ miles from Lecco. Inclusive of Abbadia and Colico, there are five transforming stations upon this branch, averaging five miles apart. At Abbadia there are two transformers installed, double power being required for the large amount of shunting done in the Lecco terminus, where all the goods traffic is dealt with, besides the work of the repairing shops.

10. There is only one primary line—three wires—to feed the whole length, this one line being simply led through the transformer-houses, and tapped in each of them. For example, at Colico the line descending the valley from the central station branches into three in



A Switch AG Amperemeter for exciting current AW Amperemeter for alternating current BV Horned lightning conductors EA Earth switch D Impedance coils HA High tension switch HR Excitation rheostat regulator MA Magnetic cut-out LZ Energy meter S Safety fuse SV Synchronising voltmeter SpS High tension safety fuse SpT Transformer of pressure V Voltmeter VU Switch of the voltmeter T Transformer WZ Wattmeter W Resistance

Fig. 250—Main Switch-board Connections.

the Colico transformer-house. One branch leads on towards Lecco, a second towards Chiavenna, and the third to the Colico transformer. In each of these branches is inserted a high-tension switch of the two-horn spread-arc type, with vertical motion of the contact blade, placed at a high level in the hinder room of the house, and operated from the front room by rope gear. In Fig. 261, which is a diagram of the transformer connections, these switches are marked B, B, B. Each transformer-house consists of two lofty rooms of small area, separated by a brick partition wall from top to bottom. The back room contains all bare high-tension parts and all the high-tension safety fuses In the front room stands the stationary transformer

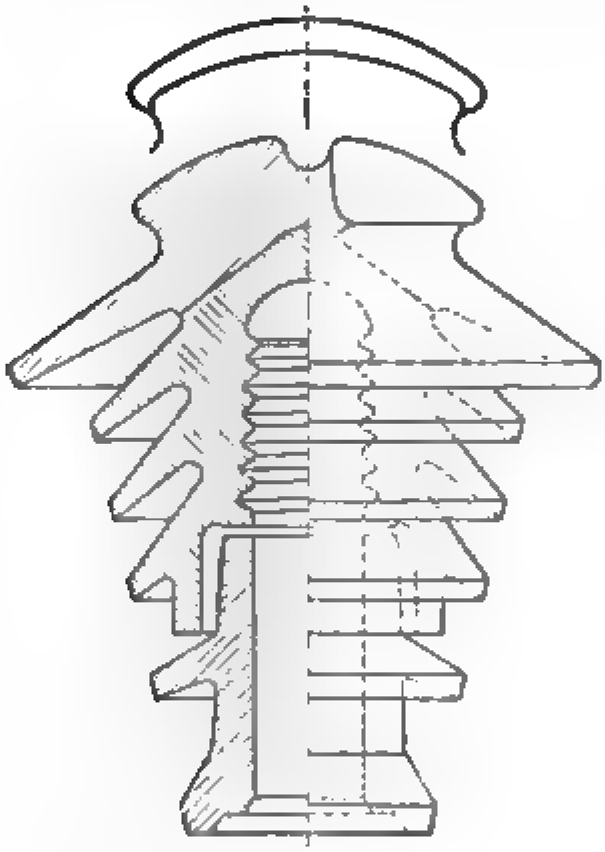


FIG. 260.—Pole-insulator for 20,000 volts.

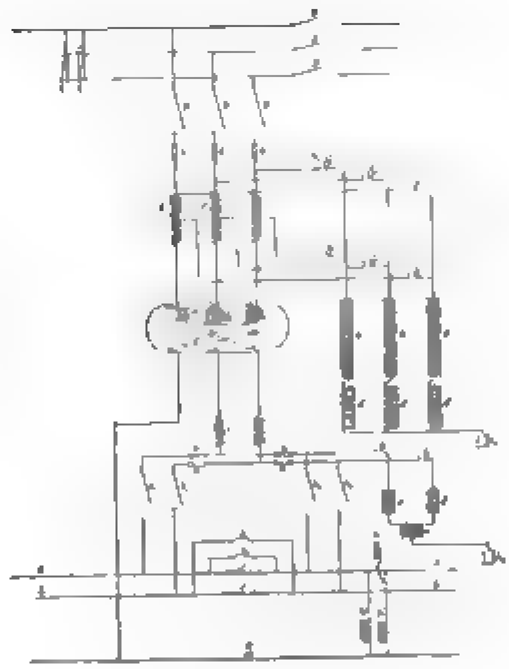


FIG. 261.—Transformer Connections.

and the low-tension switches, which are placed high up and worked from below by rope gear. In the back room is placed a ventilating fan, driven by a low-tension 14-volt 3-phase motor, which is fed by a small auxiliary winding on the transformer. On the branch of the primary leading to the transformer is inserted a set of three safety fuses, marked A, A, A on Fig. 261, which, however, does not refer to a junction like Colico. Past the transformer, one of the three secondary wires is immediately earthed—that is, led to the travelling rails, marked S on Fig. 261—while on the other two are inserted safety fuses, *a*, *a*. Beyond the latter, at Colico, the secondary line, consisting of two wires, branches in four, three branches going

towards Lecco, Sondrio, and Chiavenna, and the fourth to Colico railway station. Each of the former three branches is separately protected by pairs of fuses. The Chiavenna branch is derived by two separate and alternative routes, on which are placed two separate cut-out switches, from the Lecco and the Sondrio branches. The fourth branch to the station has its switch in the station. At each station a section of the contact line, about $\frac{4}{10}$ mile long, is insulated

Fig. 262.—Tunnel on Valtellina Railway with High-tension Line outside on hillside.

from the rest, and remains uncharged except when a train is coming in or is leaving the station. Thus at Colico, on the secondary, there are four double switches in the transformer-house—as well as the three triple high-tension switches on the primary—and a fifth in the railway station.

Thus it will be understood that there is no complicated system of feeders; there is one single feeder for the whole 67 miles, and, so far

as the primary is concerned, nothing could be of greater simplicity. For repairs or other like reasons, however, the whole length may be cut into sections by the switches already mentioned. The 8-millimetre size down to Colico gives a sectional area of 50 square millimetres, while the 7-millimetre branches have 38½ square millimetres section. Along the former is carried the total power used in both the Lecco and Chiavenna branches, as well as that taken off at Cosio between Morbegno and Colico; but on this portion the variations of

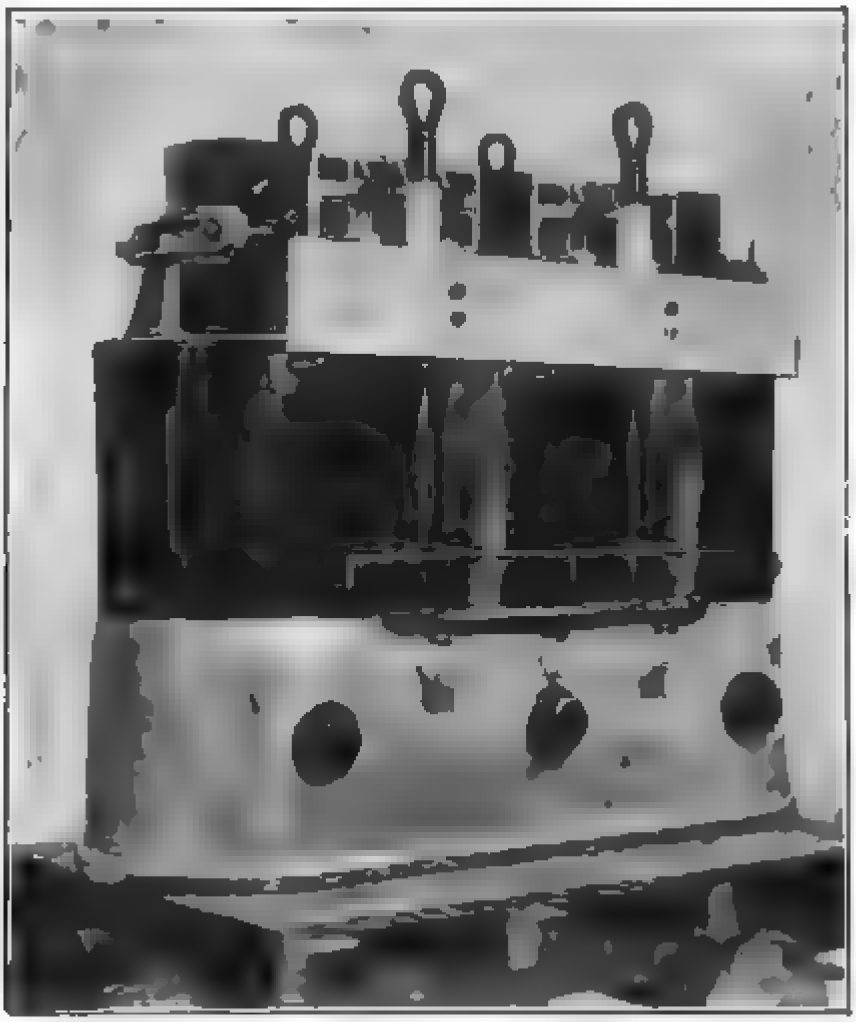


FIG. 263.—Three-phase Transformer, 20,000/3000 volts.

load on all the transformers are super-imposed, and therefore to a considerable degree levelled off.

The high-tension primaries are not taken through the tunnels, for various reasons, among them risk of damp affecting the installation. Fig. 262 is a photograph of a tunnelled part of the line, which shows how the primary is carried over the hillside outside the tunnel. The whole length of the primary is of soft copper.

Fig. 263 is a photographic view of the transformer itself. The ventilating fan—already mentioned—discharges the cooling air; upwards, through central ducts in the three parts of its body. Referring

to Fig. 261, it will be seen that between the fuses A and the primary coils G the currents pass through impedance coils, C. From points between A and C, and from the middle points of C, wires lead to the lightning conductors F, of the horned type. Each of these three pairs of wires unite beyond the lightning conductors and lead through air-spark condensers, D, E, to the earth plate L_1. Of the three wires coming from the secondary coils g, g, g, one leads straight to

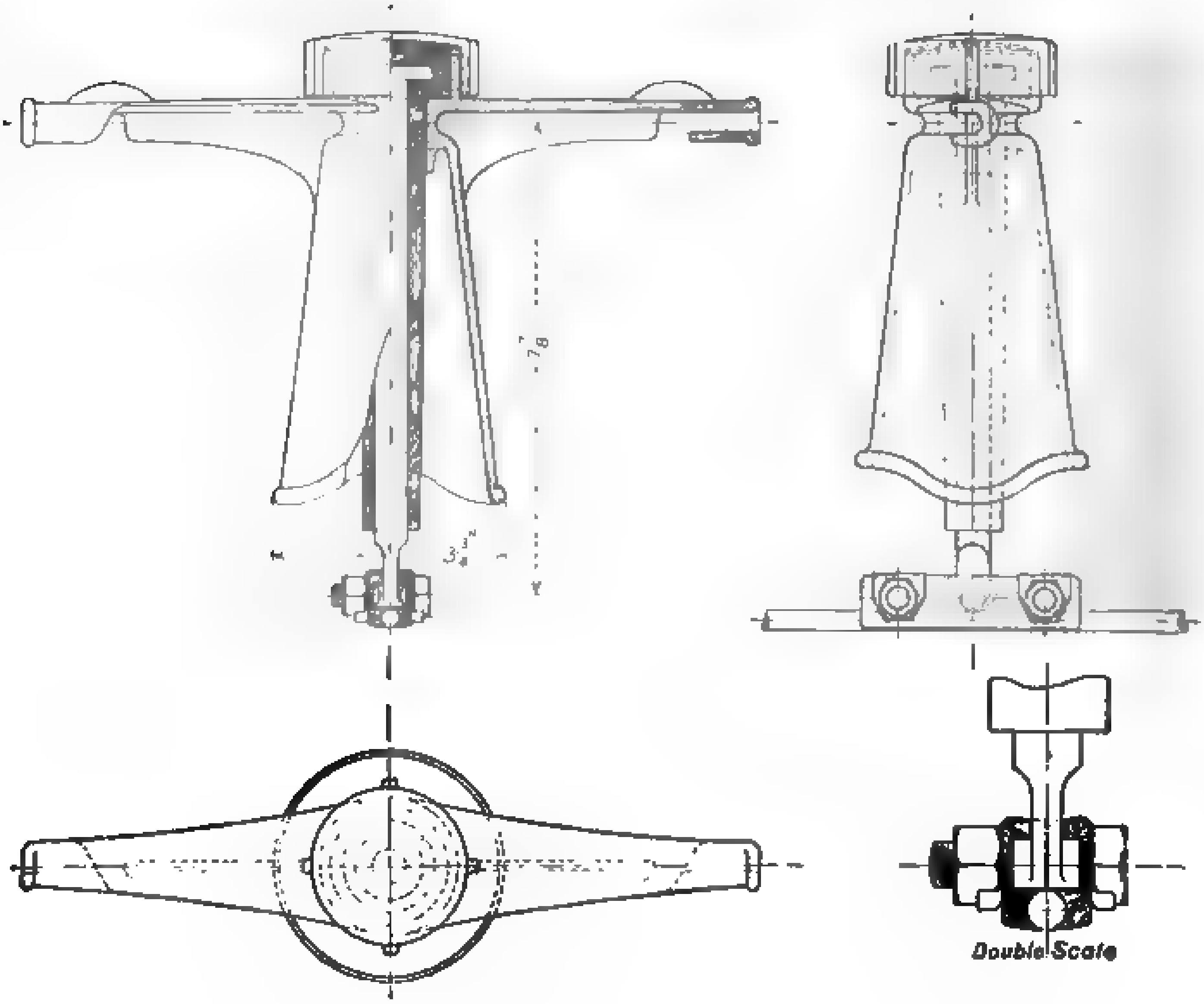


FIG. 264.—Ambroin Line-suspension Insulators, 3000 volts.

the rails S. The two others pass through impedance coils c, c, and safety fuses a, a, to the three pairs of switches b_1, b_2, b_3. Beyond b_2 the wires branch off to lightning conductors f, f, whence the path of escape is through the air-spark condensers d, e to an earth plate L_2. The trolley contact wires are marked s s. Each of them is interrupted by a short insulating length, marked J, J in the diagram, bridged across by the switches b_3, b_3. By opening these switches and one or other of the switches b_1, b_2, the contact line to either side of

the transforming station can be cut off and isolated in case of mishap or for repairs, without interfering with the activity of the line to the other side of the station.

The transformer itself can also be completely isolated from both the high-tension and low-tension lines. Thus, when a transformer is undergoing repair, no interruption to the traffic or any part of the line is necessary, the portion of the contact line near the transforming station which is cut-out being fed from the two neighbouring transformer stations. Again, all the nine transformers being inserted in parallel across the high-tension system, any specially heavy load taken off one part of the line is not borne solely by one transformer but is really distributed over several.

The normal power of each transformer is 300-kilovolt-ampères, and for a short time it can stand five times this load without overheating.

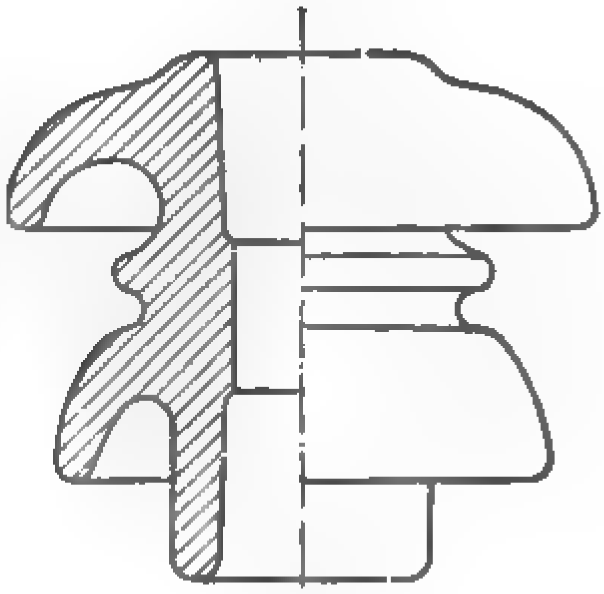


FIG. 265.—Cross-wire Insulator on Poles, 3000 volts.

11. The two overhead contact wires are of hard-drawn copper wire of 8 millimetres diameter, and are suspended 34½ inches apart by an elastic suspension of 5 millimetres galvanized steel cross wires. Each contact wire has its separate cross-suspension wire, this having for its main reason increase of mechanical elasticity in the suspension, but also having the advantage of greatly raising the insulation between the two wires, which is actually eight to ten times as much as is given by a single insulator. The attachment to the cross wires is by means of ambroin insulators of the design shown in Fig. 264. The outside protection is a cast-iron bell. The supporting pin is a ½-inch galvanized steel rod, covered with 8 millimetres thickness of ambroin. At its lower end this pin is hinged to the two-part metal clamp in which the contact wire is secured. Thus, as the trolley passes the insulator, the wire is free to swing out of the horizontal without the insulator itself being pulled out of its vertical position. This is of some importance, as the mechanical force upon the insulator does not pull it so as to let the wire accommodate itself in the right way to the passage of the trolley. The insulators used at curves have eyes cast on their lower edges for the attachment of cross steady wires. At butt joints of the line-wires no soldering is employed, screw clamps alone being relied on. These ambroin suspension

insulators are all tested to 10,000 volts. Each end of the steel suspension wire is fastened to a porcelain insulator, shown in Fig. 265, which is tested to 12,000 volts. The three methods of support are

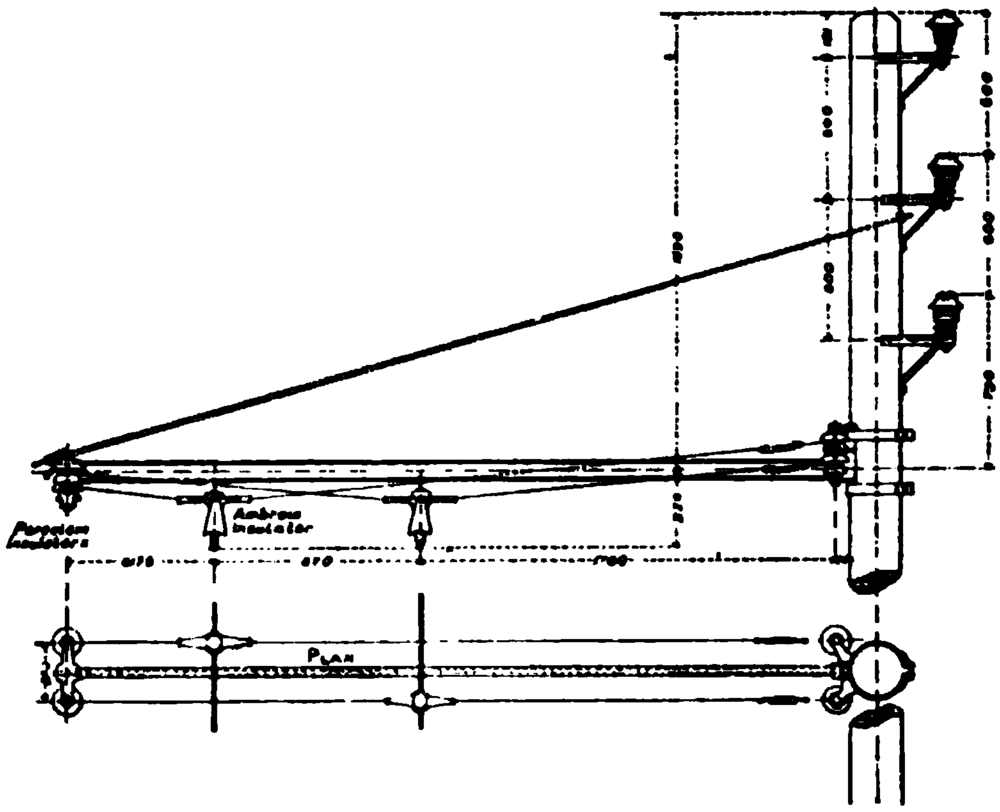


FIG. 266.—Single Post Support for Conductors.

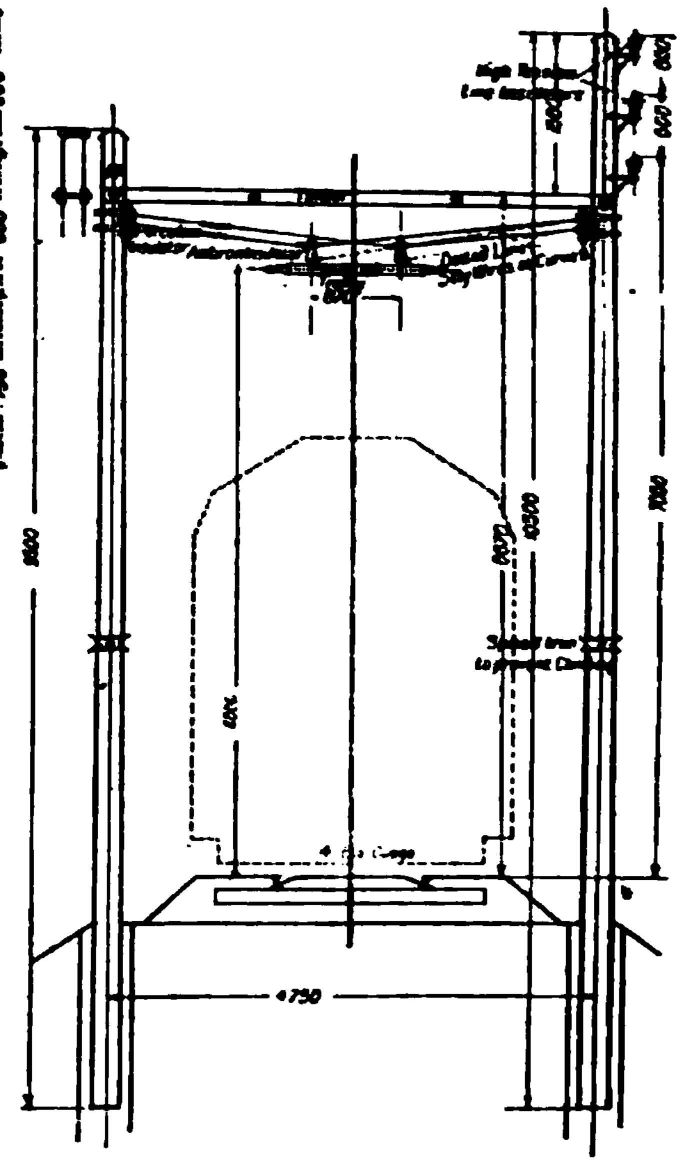


FIG. 267.—Double Post Support.

shown in Figs. 266, 267, and 268, which also show the attachment of the high-tension three-wire line to the same posts. The stretch from Lecco to Colico along the lake side is much exposed to wind, and here, as also in the sharper curves elsewhere, double posts braced across at top—see Fig. 267—by two light wood rails are employed. In the upper valley the single-post system—Fig. 265—is used. The single post with two arms, as in Fig. 268, is used in stations and sidings where the line is double. The posts are spaced on the average forty per kilometre, or sixty-four per mile. At intervals along the line both high-tension and low-tension lines are protected by lightning conductors on the posts, the path to earth being through liquid resistances in cylinders carried by the posts somewhat above their middle height.

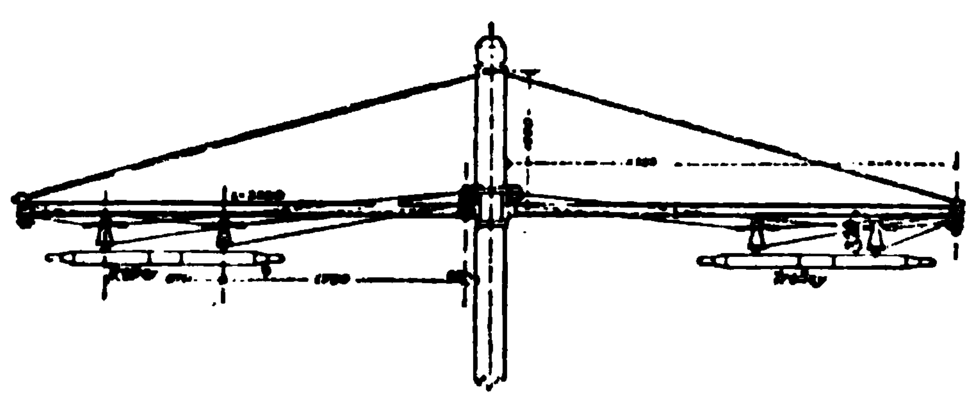


FIG. 268.—Two-arm Pole.

In the tunnels, owing to the small headway available, the suspending wires stretch longitudinally, the porcelain insulators to

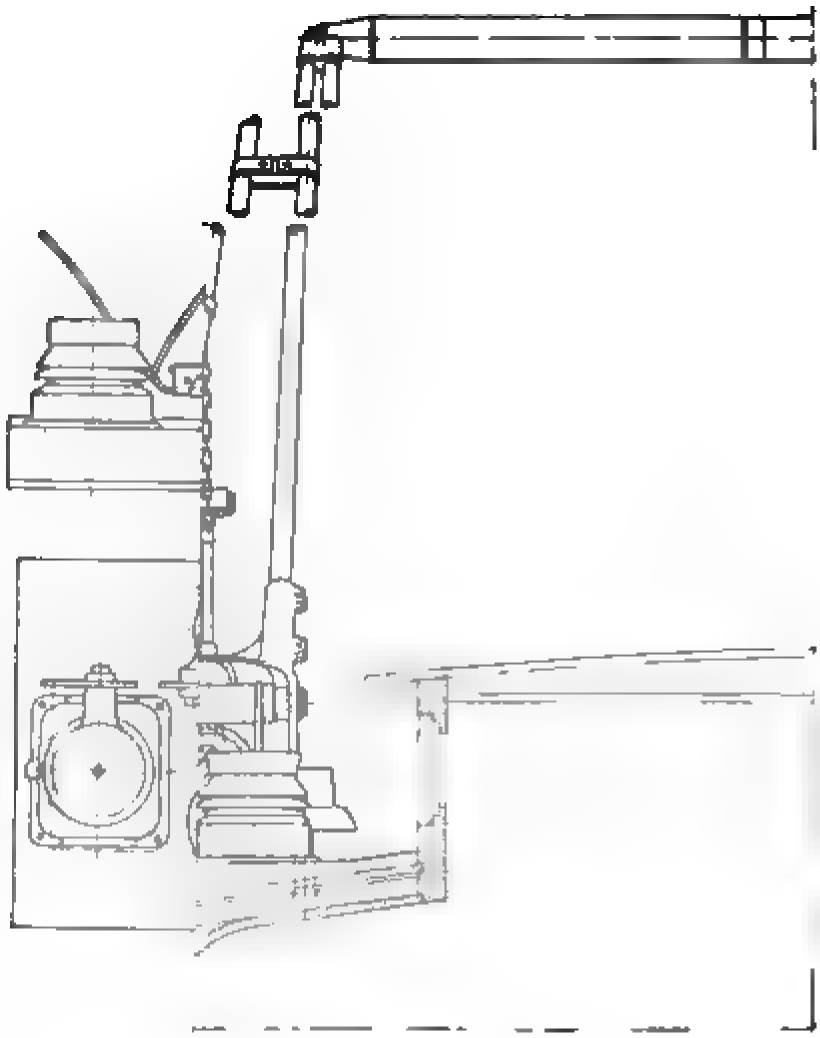


Fig. 270.—End View of Trolley.

[To face p. 373.

which they are tied being fixed in the soffit of the arch by bolts cemented in.

12. As already mentioned, the contact line is in sections, united only through the switches mounted for this purpose. At each station there is a "station-section," stretching 1050 feet on either side of the station, and the long sections are thus 2100 feet shorter than the distances between stations. On the track itself each gap is filled up by a creosoted hardwood stake 2 feet long. Similar longer wood insulating pieces are also inserted at all crossings, etc., wherever one wire has to pass another, only one of the two crossing wires, however, being so interrupted. At such crossings, of course, electric continuity is maintained by a copper junction wire passing over the wood, the wood merely keeping the trolley temporarily out of contact. To avoid sparking, the junction wire is raised some inches above the wood. The third phase passes along the travelling rails, which are bonded by bent copper wire 6 millimetres thick, pegged by unsplit steel pins into conical holes drilled in the rail ends. At every half-kilometre the two rails are cross-bonded by copper strip. The insulation of the whole 3-phase system, high and low tension together, is tested by raising the voltage at the central station to 30,000 volts.

13. Fig. 269 is the elevation and half plan of the trolley, and Fig. 270 is a half end view of the same. The two contact rollers run upon one axle pole, 65 inches long, of hard wood saturated under pressure with a special hard grease, the two being separated by 9 inches length of insulation. Each contact roller is an electrolytic copper cylinder, 3¼ inches diameter by 26 inches long, revolving upon hard-steel ball-bearings. This pole and pair of rollers are best seen in Figs. 279 and 280, the end views of the locomotive. At its outer end a collar upon the copper cylinder rubs upon, and conducts the current to, a fixed ring-block of carbon, whence it is led by a covered cable inside the tube forming one arm of the trolley frame, to the cast-iron trolley base-plate, and thence again through well-earthed metal tubes to the main working switch. The covered cable is kept in the centre of each such tube by being threaded through series of porcelain spheres. The trolley base-plate is insulated from the car roof, to which it is bolted, by three-lipped porcelain insulators. Each of the two arms of the trolley frame is made of two Mannesmann steel tubes. Each is 9 feet 9 inches long. The frame allows considerable latitude to the cross pole carrying the rollers to tilt out of horizontal, so as to accommodate itself to want of level between the two contact wires.

A glycerine cataract, marked K in the drawings, prevents violent impact of the trolley either upon the overhead line when it is raised, or upon its bearing upon the car roof when it is lowered, the former buffer action being exerted through a short chain. Each arm of the frame is independently pulled up by a pair of springs; but these

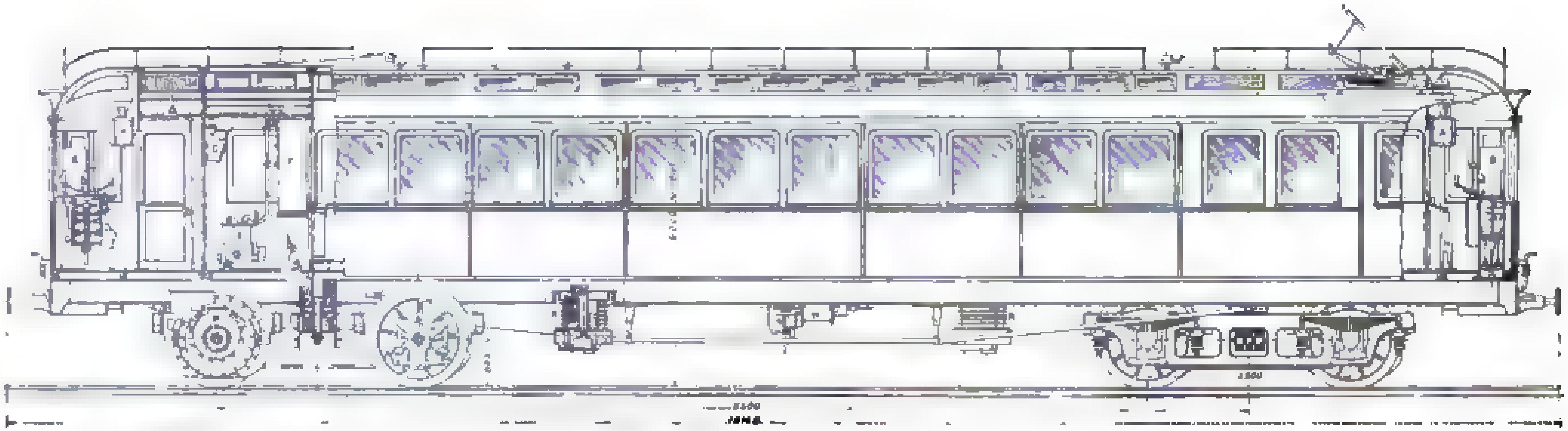


Fig. 271.—High-tension 3-phase Motor Railway Carriage.

springs take, through an equalizing cross-beam, their abutment upon the plunger of an air cylinder. It is by exhausting and filling this air cylinder that the driver lowers and lifts the trolley, and it is only by opening the air valve that he has any power to move the trolley arm. In certain contingencies, involving danger, the air is exhausted automatically so as to cut off current from the motors; and the air-supply cock can be opened by the driver only if a specially cut key —of which there is no duplicate—be inserted. This same key opens the doors of the main switch housing and of the fuse-box, and cannot be withdrawn from the lock except after each of these doors has been closed. This housing and the fuse-box contain the only bare parts of the 3000-volt transmission, it being everywhere else permanently enclosed in well-earthed metal casings. It is thus automatically impossible for the driver to touch any live part of the apparatus.

Each motor-coach and each locomotive carries two trolley frames, each used normally for travel in one only of the two opposite directions. But in passing siding switches, crossings, etc., there are wood insulators, sometimes of considerable length, inserted in one of the two contact lines; and at these places it is often useful to have both trolleys raised, one of the two always being outside the insulated length.

14. Fig. 271 is an elevation of a motor-car, in which the driver's two cabins, one at either end, one liquid rheostat R, and one driving-axle are shown in section. The two rheostat-boxes have external cooling ribs cast upon them. The liquid is a solution of sodium carbonate. It is gradually raised into contact with specially shaped iron plates by the injection of compressed air.

In Fig. 271 W is the Westinghouse air-brake cylinder. The air for the brakes, the rheostats, trolleys, and the numerous manipulations which are all operated pneumatically, is stored in the reservoir F in the cabin behind the driver's cabin, into which it is pumped by the two-stage compressor E, driven by a direct-coupled 3-phase 100-volt 8-kilowatt motor, to which current is supplied by a small static transformer carried on deck. The compressor is designed for 10 atmospheres pressure; but at Valtellina 6 atmospheres is found ample, and is the pressure normally used. An automatic governor in the case marked G, in Fig. 271, controlled by the falling and rising air pressure, switches on and off the current, and maintains the pressure within the desired limits. The compressor requires to be run about two-thirds of the whole time of travelling.

The main working 3-pole switch—contact being broken at six points—is seen well in the photographic view, Fig. 272. The gap made by it when open is 8 inches long, and as this is doubled, it is really 16 inches from pole to pole. The six copper studs slide in six

porcelain tubes, the end of each tube having a steatite cap for the

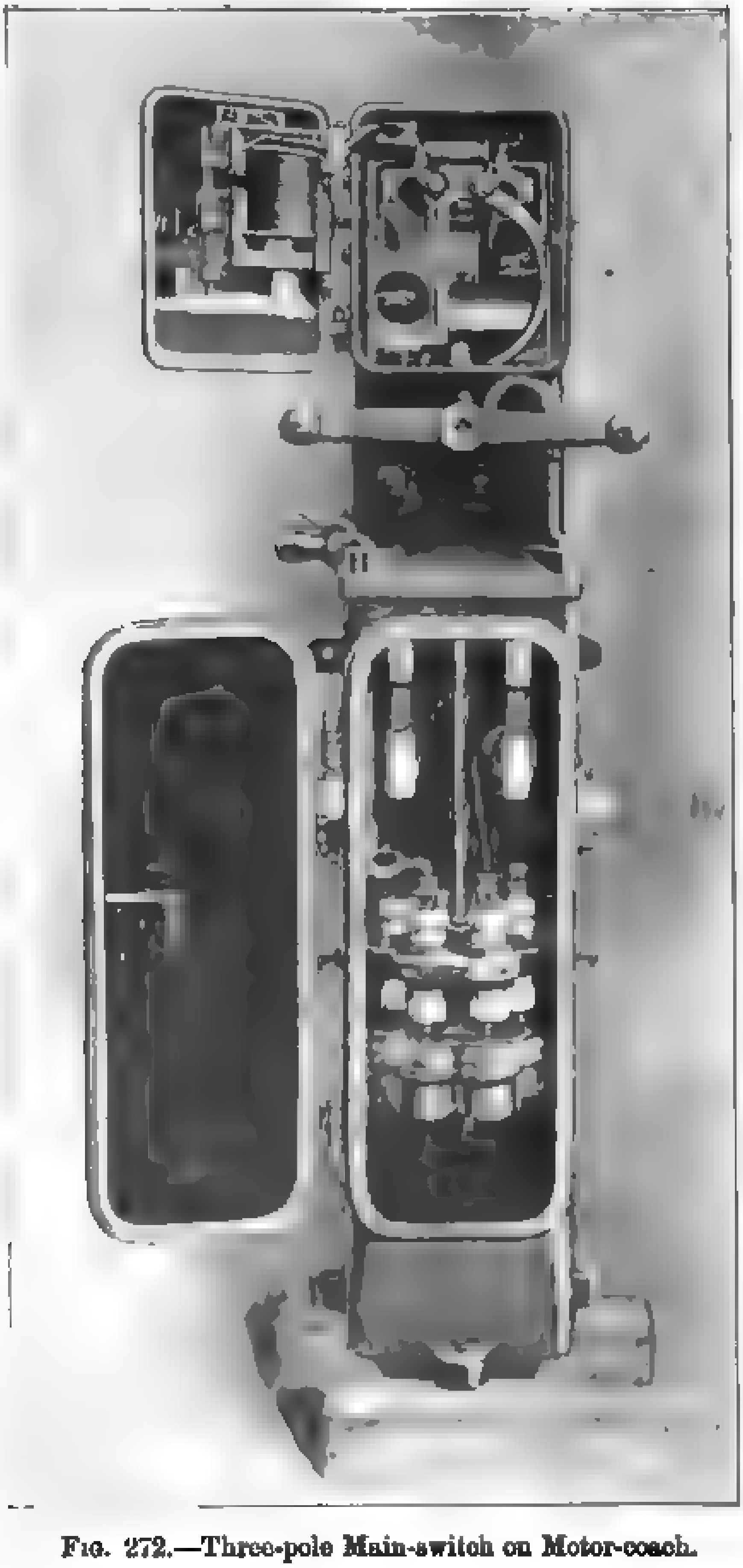


FIG. 272.—Three-pole Main-switch on Motor-coach.

sake of renewal. A photographic view of the controller is shown in

Fig. 273. In Fig. 271 the main switch is marked B, and is seen in section at the right-hand end cabin. The controller is marked C, and is shown in section in the cabin at the left-hand of the drawing. All the manipulating apparatus is duplicated in the two cabins.

The motors and all the accessory apparatus are protected by safety fuses. These are placed in the box marked A. Two lightning pro-

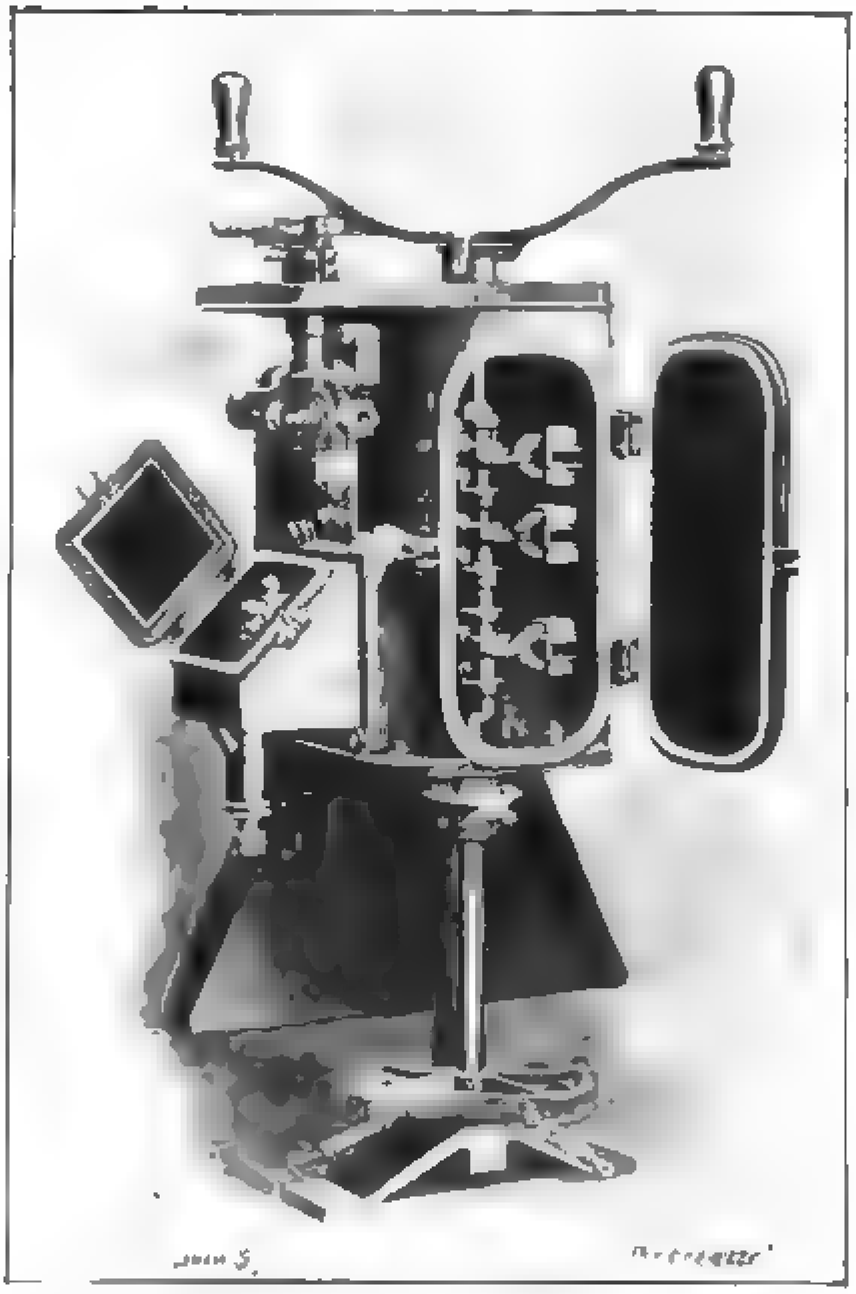


FIG. 273.—Controller on Motor-coach.

tectors of the two-horned pattern, seen both in Figs. 271 and 276, and in Fig. 269, are mounted on the iron base-plate of each trolley.

The wheel base of each bogie-truck is $2\frac{1}{2}$ metres, with $11\frac{1}{2}$ metres between the two bogie-pins. Over buffers the length is 19·14 metres, and the tread of the wheels is 1·17 metre. A truck with its two motors is shown in Fig. 274. Each truck carries two motors, one on

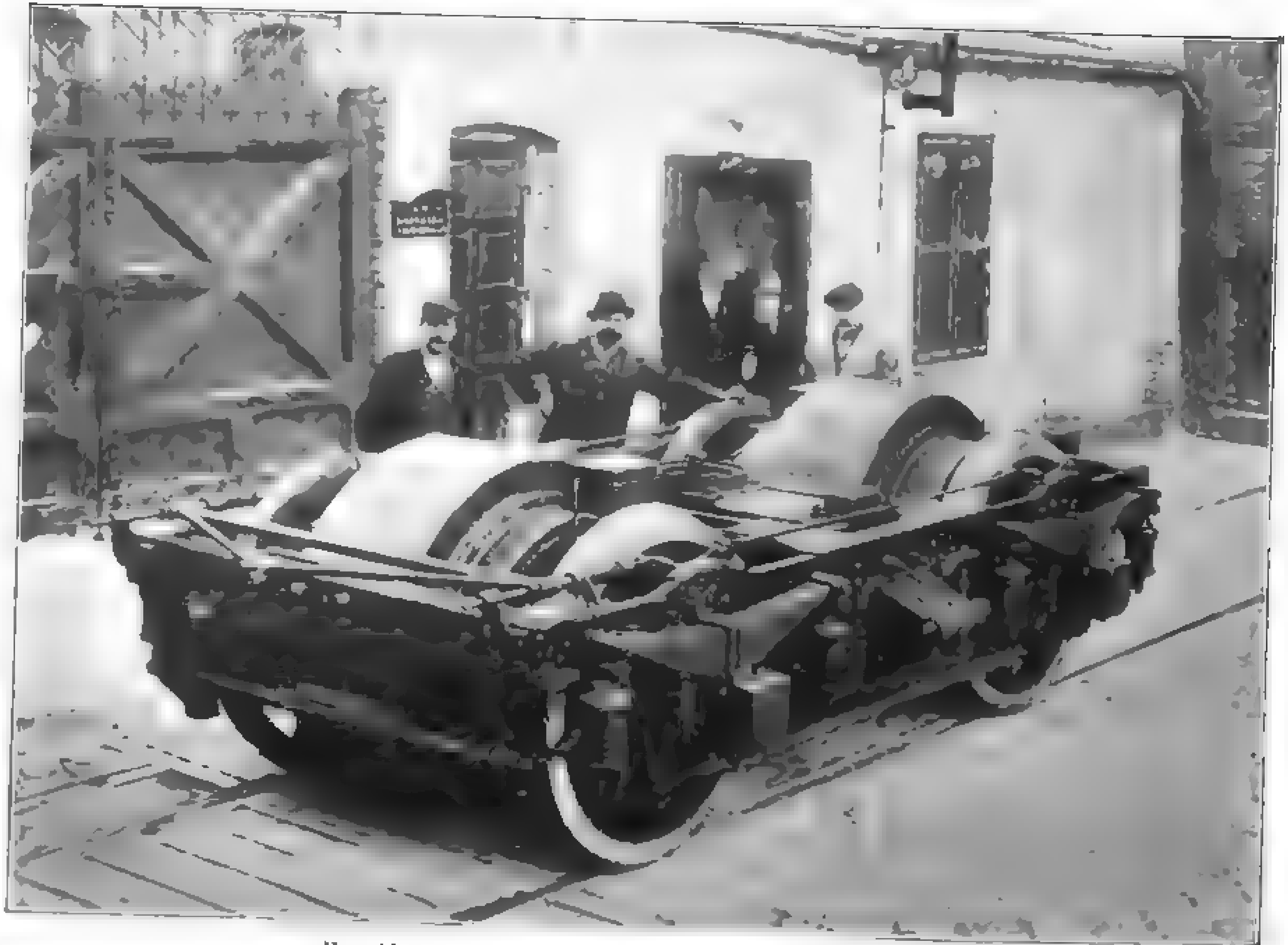


Fig. 274.—Motor Bogie-truck for Ganz Cascade Motor-coach

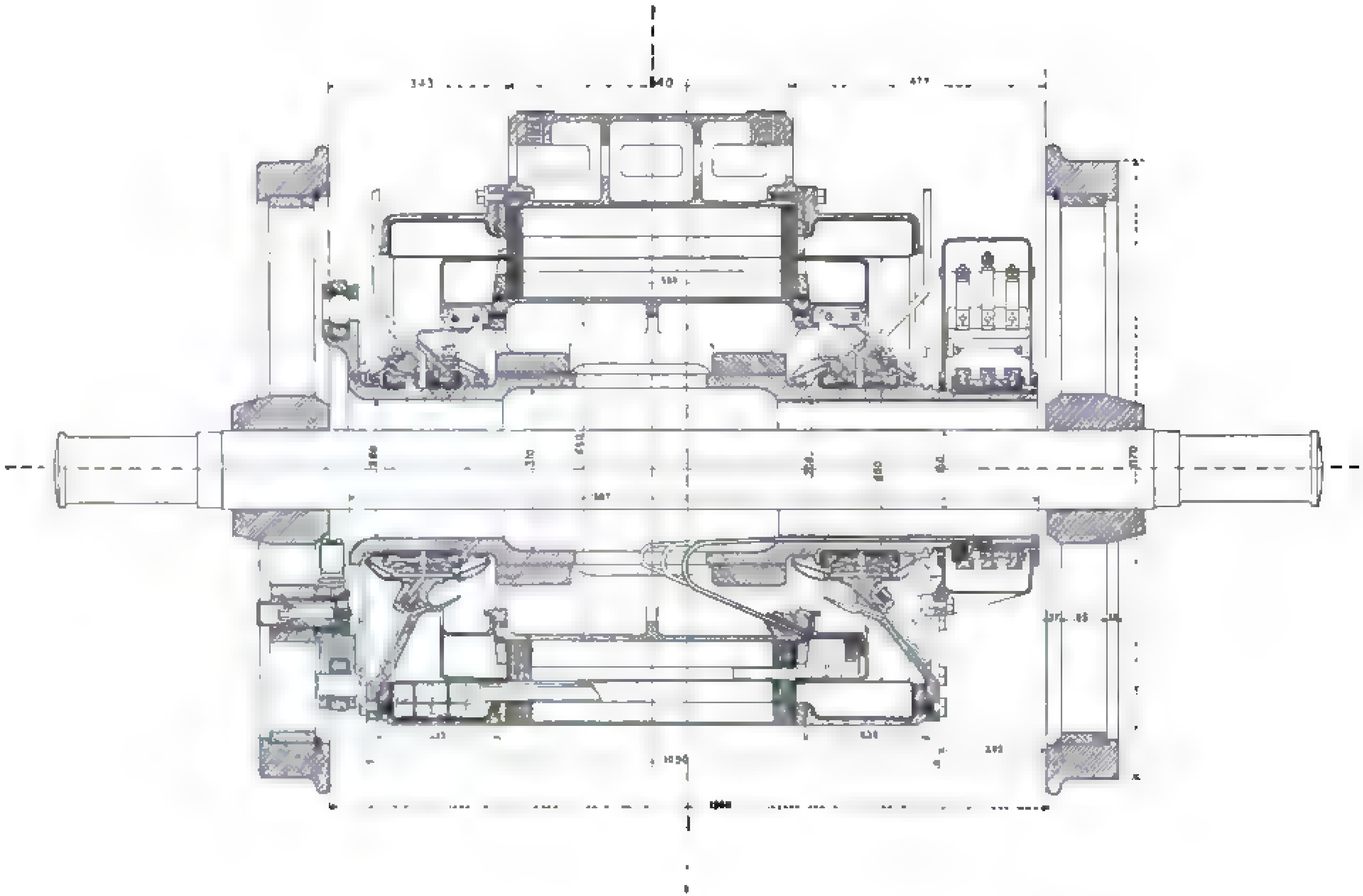


Fig. 275.—High-tension Cascade Ganz Induction-motor

each axle. These are used in cascade up to half speed, and also in slowing from full speed to half speed. During this latter period they act as 3-phase dynamos, and supply energy to the line. The pair in "cascade," the meaning of which term has already been explained, exert a normal horse-power of 150 or 300 on the two bogies. For a short time they can do 400 horse-power without damage. Fig. 275 is a section of one of these motors.

The current from each active rotor is drawn off by three bronze slip-rings with carbon collectors. As the rheostat resistance is gradually cut out by the entrance of the high-pressure air in the air-chambers of R, R, the speed rises, and the time rate of decrease of resistance is automatically varied so as to effect an approximation to

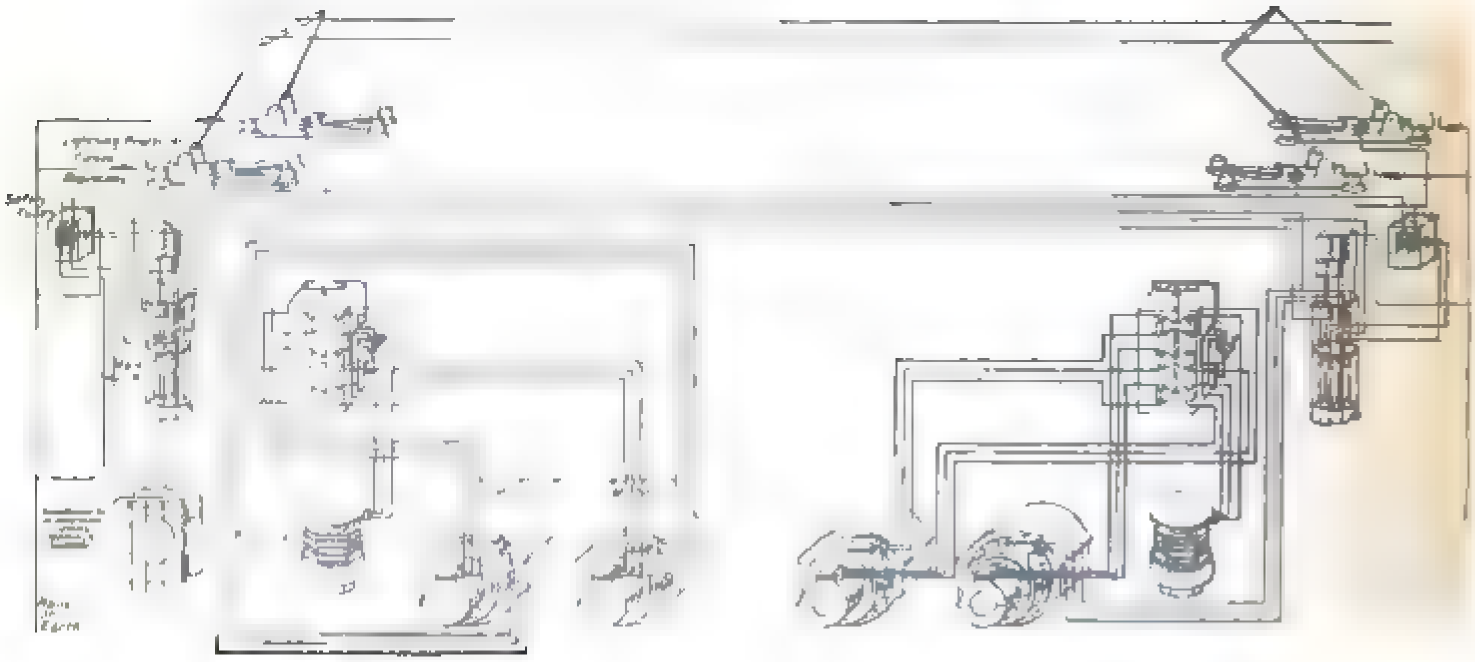


FIG. 276.—Electrical Diagram of Car.

uniform torque. After synchronous speed is reached, the rheostat resistance being now zero, if it be desired to accelerate further—from this half towards full speed—the second motor is cut out and the rheostat resistance inserted in the rotor circuit of the first, or high-tension, motor, the resistance being now again gradually decreased at an automatically regulated time rate. Thus the controlling is of the simplest kind, and, moreover, it is wholly effected in low-tension circuits. The hand lever of the controller has only three positions: (1) "Low speed," in which it stands during the period of first acceleration; (2) "cut-out," or the mid position, in which the resistance is disconnected and the first rotor circuit stands open; and (3) "full" speed, for acceleration from half to full speed. Reversal of the running direction is effected by the main switch lever B.

Fig. 276 gives the diagram of the electric connections of the whole

car. The explanations given above, and the notes on the diagram, make it easily intelligible. The controller is shown in the cascade position, the rheostat being in the rotor circuit of the second motor. The high-tension motors are on the axles nearer the buffers; the low-tension on the inner sides of the bogies. The housings of two motors are reverse-identical castings, and the two bolted together with the swivel-pin casting form an inner frame to the bogie.

15. Fig. 277 is a drawing of the very pretty parallel-link connection between the driving hollow rotor-shaft and the wheels. Each pair of wheels is keyed to a shaft whose diameter is 4½ inches less than the inside of the hollow shaft, and the link work shown in

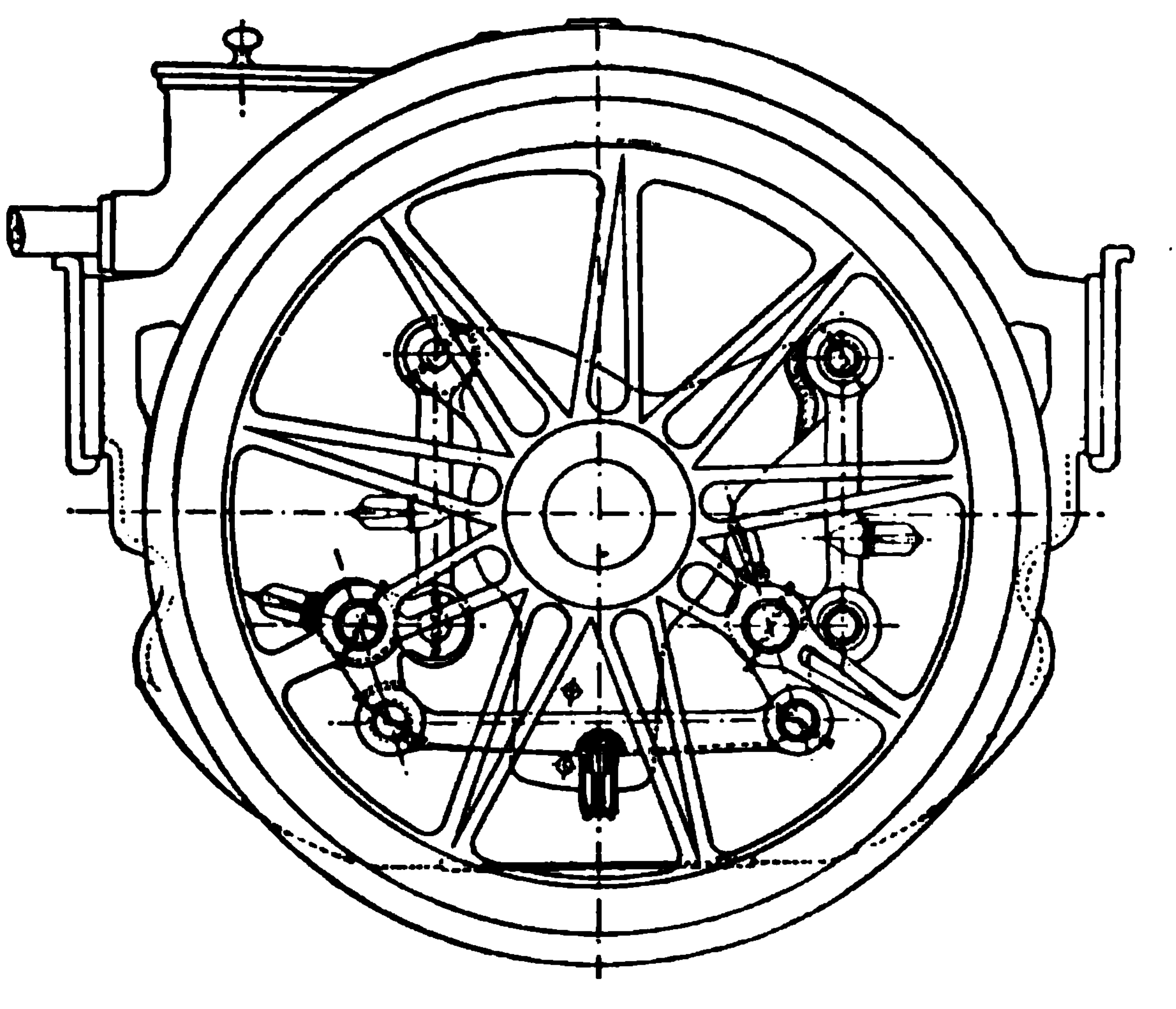


FIG. 277.—Parallel Driving Linkage.

Fig. 277 compels the two to rotate accurately together while giving complete freedom to the wheel-shaft to rise and fall with the axle-boxes between the horn-plates without any vertical motion of the rotor, stator, or motor as a whole. Thus the whole weight of the motor is spring-borne; the bearings of the rotor-shaft are fixed in the housing carrying the stator, and as small an air space between rotor and stator as is electrically and magnetically desirable is mechanically possible and as easy to obtain as in fixed plant. The limit of vertical oscillation of the wheels under the springs is the above 4¼ inches, or rather 3½ inches, allowing ⅜-inch per side clearance. The wheel is driven by a pure torque—that is, by two equal and opposite forces producing no reactive resultant pressure upon the bearings in which the rotor runs. These bearings carry no weight

except that of the rotor itself. Each rotor weighs 1½ tons. The whole load, including the weight of the rotor, is carried at the axle-box bearings.

16. In Figs. 278, 279, 280, and 281 are given drawings showing elevations and plan of the locomotive weighing 46 tons with four pairs of driving-wheels 55 inches in diameter. The whole is in two parts, which are identically reverse. Each part has a rigid wheel-base 2 metres long, and the two parts are coupled together by a central 3¼-inch draw-pin joint with rigid attachments, reinforced by two smaller side draw-pins with buffer-spring attachments. These connections are best seen in the side elevation, Fig. 278, and in the cross-section, Fig. 281, at mid-length of the locomotive. The driver's cabin is a spacious apartment, 3¾ metres long, the central portions of the walls and roofs being collapsible, while the floors of fore and aft halves are connected by a steel floor-plate hinged to the one and sliding on the other. The total wheel-base of the locomotive is 6·63 metres, or 22 feet, but each rigid portion having only 6 feet 7 inches wheel-base, the locomotive travels very freely round sharp curves.

The trolleys are of the same pattern as in the motor-car. At either end beyond the cabin over the end axle there is a compartment with a low sloping roof. This contains at each end a compressed air reservoir ½ metre in diameter, lying horizontally and transversely, and a sodium-carbonate liquid rheostat box. All four motors are alike high-tension, the cascade not being used upon the goods locomotives, and each of 150 normal horse-power, with from 30 to 40 per cent. overload capacity. The locomotive is thus of 600 normal horse-power, and is capable of drawing from 400 to 500 tons up the steep inclines of the line when the rails give sufficient adhesion. The rotors drive the wheels by the same style of parallel link-gear as seen in Fig. 277, the dimensioning of the linkage being somewhat stronger in this case, as seen in outline in the two end wheels in the elevation of the locomotive. The controller and other driving apparatus is not duplicated as in the motor-coach; but each manipulating lever, wheel, or handle is duplicated, so that the driver may stand at one or other end of the cabin always looking forwards in whichever direction he is travelling. Fig. 282 is a photographic view of the controller and other driving gear. During shunting work both trolleys are kept raised against the overhead contact wires. The controller gives the driver power to manipulate the four motors independently, so that one, two, three, or all of them may take power and assist in driving. To start a 270-ton goods train up the 11 per 1000 Chiavenna incline the locomotive takes 150 ampères. These locomotives have, of course, only one synchronous speed, corresponding to about 30 kilometres per hour travelling speed. They are used

Fig. 280.

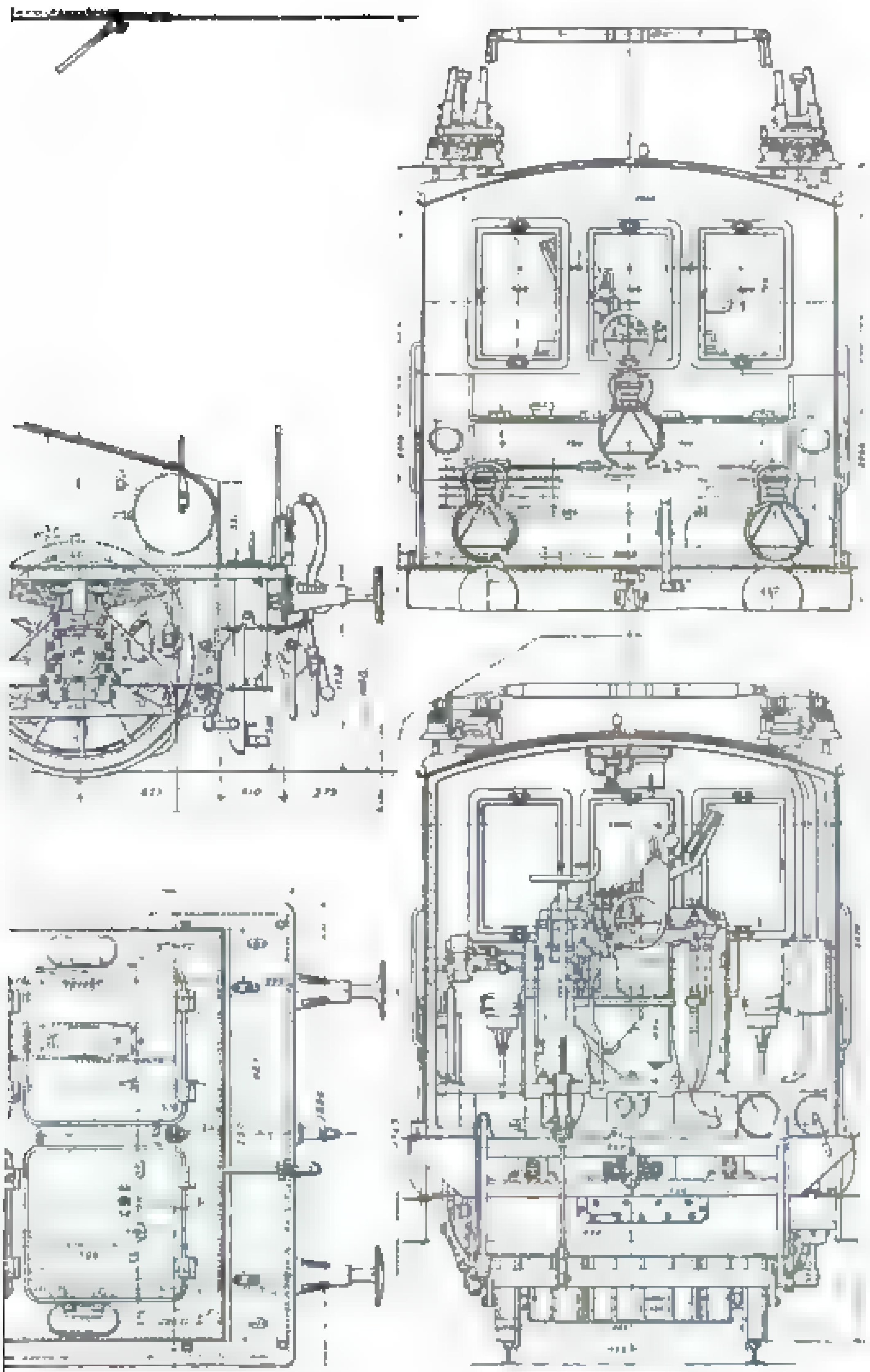


Fig. 281.

altellina Railway.

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for goods traffic only. The later design of locomotive introduced for high-speed passenger express trains is described below.

17. The line is worked on a block system, which is partly electric and automatic. In and on either side of each station is an insulated section of the contact wires, which remains dead except when a train is coming into, or is leaving, the station. In coming in, if the signal is not against it, the approach of the train switches in the station

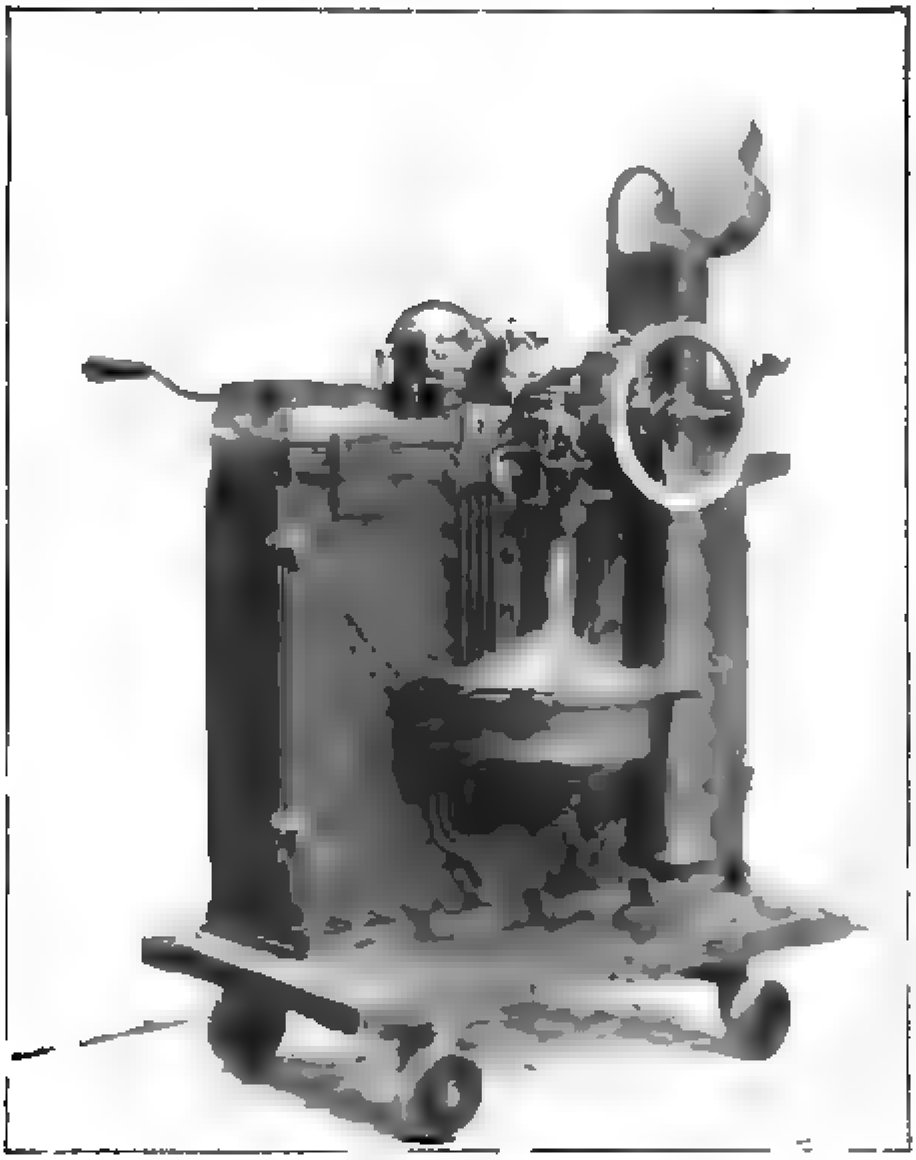


FIG. 282.—Controller on Locomotive.

section. When the train stops, it becomes again dead; and in order to start the train out the switch has to be once more closed. In travelling through each section, the train carries a metal cylindrical staff with a number of external collars, the spacing of which identifies it as belonging to that one particular section, and to it alone. To each section belongs a definite number of identical staffs. At each end of the section on the station platform stands a slotted pillar staff-holder, shown in Fig. 283, containing a special mechanism of simple

character not liable to get out of order. There are two such pillars in each station, one for each of the two neighbouring sections. The two pillars in the two stations at the two ends of one section are connected electrically by a special wire and small battery in such a way that the two mechanisms always move and stand alike. The mechanism, which is seen in two views in Figs. 284 and 285, offers no hindrance at any time to a staff being put into the holder, and both mechanisms are moved by a staff being deposited in either of them—it does not matter which. The common position they assume depends on the combined number of staffs deposited in the two holders. When all the staffs belonging to the section have been deposited at one or other end of it, then the mechanisms have been brought into the one only position in which they allow a staff to be extracted; in all other positions their slots remain closed against such extraction.

As seen in Figs. 284 and 285, the mechanism contains five hanging levers and five circular discs, these latter being all fixed on one horizontal spindle. The middle disc is cut with four ratchet

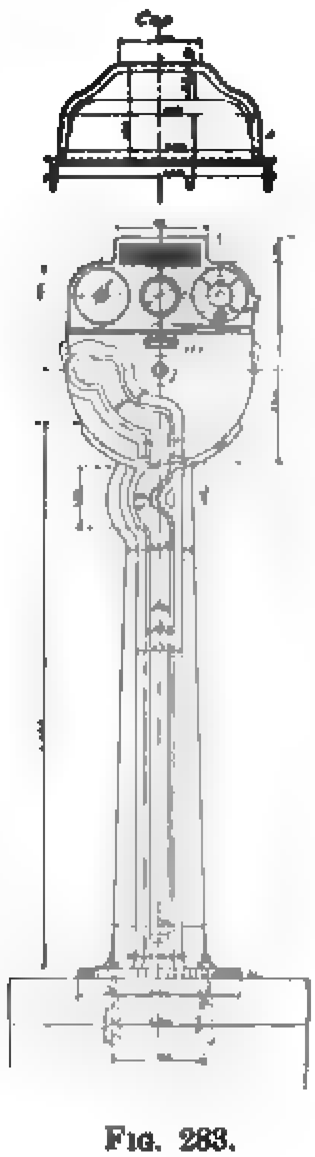


Fig. 283.

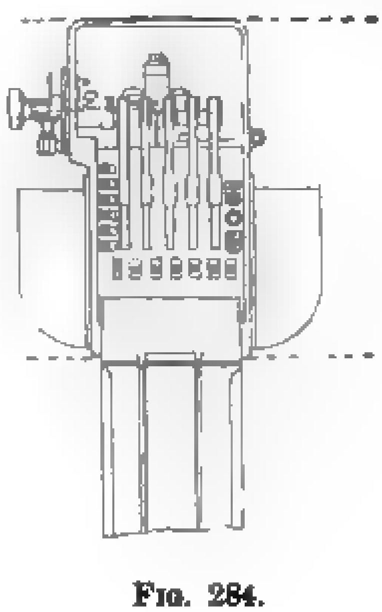


Fig. 284.

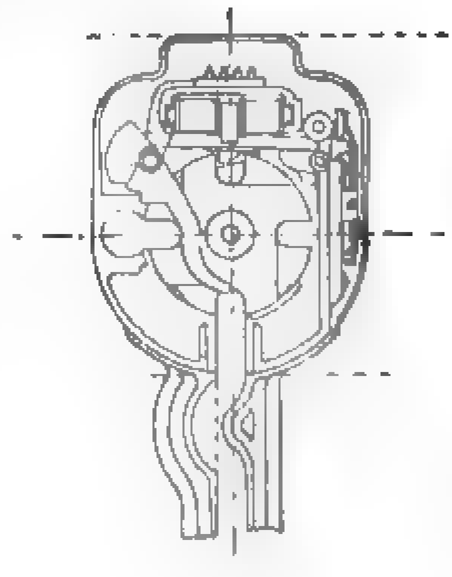


Fig. 285.

Staff Pillar of Block System.

teeth. A corresponding tooth upon the underside of the horizontal lever-armature of the electro-magnet, seen at the top of Fig. 285, prevents rotation right-handedly, except when this armature is raised by the passage of two currents in the same direction through the two coils of the electro-magnet. These currents come from two batteries, the "line" battery mentioned above and the "relay" battery to be spoken of immediately. The other discs, and the outer four of the

hanging levers, form a commutator, the various positions of which determine the passage of these currents from the batteries. When the two currents pass in opposite directions the armature-tooth is not lifted. Each of these outer four discs is cut with four notches in its periphery. When a staff is inserted it enters one of these notches, and, in being pushed down through the upper quadrantal part of the slot, it carries the disc-spindle left-handedly through a quarter turn. The middle lever, which alone is seen in Fig. 285, acts as a pawl, preventing the extraction of a staff, except when drawn aside by the action of the electro-magnet.

Thus, as the deposition in these holders of all the staffs belonging to the section means that the section is empty, a train driver is unable to get a staff permitting him to proceed along the section unless that section be empty. Further, to the mechanism of each pillar is attached a second small relay battery, whose circuit is closed by the action of withdrawing a staff. The current on this battery circuit operates the station switch—to close it—which gives 3000-volt tension to the insulated station section of the overhead wires; so that the driver cannot get his voltage to start away from the station without first taking his staff out of the holder.

18. The whole cost of this Valtellina electrification was about £248,000. Of this, £100,000 was spent upon the hydraulic power works, which, it must be remembered, are capable of at least three times as much power development as it is at present called on to provide. Over £52,000 is accounted for by the electric rolling-stock, while £68,000 was spent upon the electrification of the line. The central station machinery enters the account for the remaining £28,000. The £248,000, divided by the 67 miles length, gives £3700 per mile; but if we take the developments capable of being served by the existing hydraulic works and the central station plant, the cost works out to a figure less than £2000 per mile of single track.

The latest available returns based upon the accounts for nine months' working, from January to September, 1903, show an energy consumption of 2,198,000 kilowatt-hours for 48,100,000 ton-kilometres actual traffic, or 45·7 watt-hours per ton-kilometre. The following is the power-station expenditure account for this period, reduced to per 1000 ton-kilometres.

WORKING COST OF THE POWER STATION.

	Per 1000 actual ton-kilometres. Centesimi.
Staff	31·5
Oil	2·0
Taxes, insurance	4·15
Lighting, cleaning material	0·43
Office utensils, etc.	0·62
Freight expenses	0·24
Up-keep of—	
Electrical machinery	1·17
Turbines and piping	1·52
Canals	1·57
Travelling, personal expenses	0·62
Tools and apparatus	0·46
	44·3

i.e. per kilowatt-hour, 0.97 centesimi.

To this there is to be added the cost of the line working, as follows:—

COST OF UP-KEEP OF THE LINE EQUIPMENT AND VEHICLES.

	Per 1000 actual ton-kilometres. Centesimi.
Staff—	
On the line	32·5
In repair shop	17·52
Oil	0·21
Telephone, office, postage	1·03
Transformers	2·03
Up-keep of—	
Vehicles	9·44
Of primary and secondary line	2·89
Tools	1·12
Travelling	1·18
Lighting of stations and vehicles	1·24
Taxes, insurance	11·5
Accumulators	3·50
Repair shop	3·50
	87·7
	Add 44·3

Centesimi per 1000 ton-kilometres, 132

or 1·92 centesimi per kilowatt-hour

Add 0·97 „ „ „

2·89 „ „ „

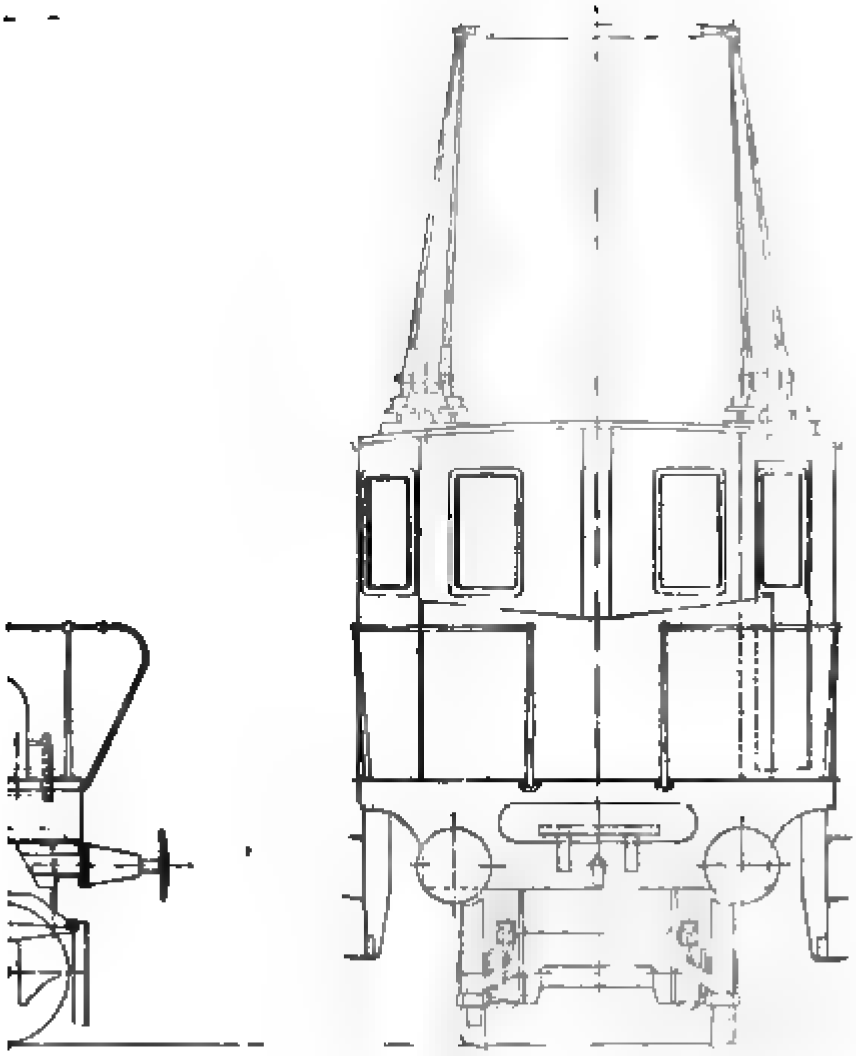


FIG. 287.

ina Railway.

[*To face p.* 387.

Taking 1 lira, or 100 centesimi, as equal to 10*d.*, these costs are equivalent to 2·9*d.* per British B.T. Unit, and to 1*s.* 9*d.* per 1000 ton-miles.

Before the electric conversion, the cost of coal alone to the locomotives on this Lecco line was 3*s.* 1*d.* per 1000 ton-miles.

19. The new locomotives for express traffic are entirely different in design to those above illustrated. Figs. 286 and 287 give elevation and end view of one of them. They are rated at 1600 horse-power. The driving-wheel diameter is 1·450 metre, and the full speed is 64 kilometres, or 40 miles, per hour. Each locomotive weighs 62 tons, with 42 tons on the drivers. Cascade motors are used, with 3000 voltage and 15 per second frequency. The synchronous speed for the low-tension motor when in cascade working is reached at 32¼ kilometres per hour travelling, and for the other motor at 64½ kilometres per hour when the low-tension motor is out of circuit.

The total length of the locomotive over buffers is 11⅓ metres, and the total wheel-base is 9½ metres. As seen in Fig. 286, there are three driving-axles, and beyond them a pony-axle at each end, the whole being thus a ten-wheeled locomotive. The motors are mounted on a sixth and a seventh axle, lying between the three driving-axles and at a higher level. These motor-shafts are cranked, and both of them drive on to the middle driving-wheel axle by means of connecting or coupling rods. This middle axle in its turn is coupled forwards and backwards to the two other driving-wheel axles.

In consequence of the interposition of the coupling-rods, the bearings of the motors may be built rigidly into the truck-frame without the need of any linkage or other device such as that of Fig. 277; and this is a great advantage to the machine as a whole from the point of view of smooth and efficient mechanical working. The three driving axle-boxes are free to swing vertically in their horn-plates quite independently of each other, that is, complete independent freedom is given to the spring suspension of the truck over each axle. The whole character of the suspension and of the driving gear becomes much more like those of the standard types of steam locomotive. These results are obtained, however, at the expense of introducing two dead-points per revolution in the driving action of the coupling-rods. The general pattern may, however, give facility of economical conversion of standard steam locomotives to electric traction.

Each pony-axle and its neighbour driving-axle are mounted upon a bogie-truck with swivel-pin. The swivel centre of the leading truck is rigidly fixed in the underframe of the locomotive, while that of the trailing truck is allowed some lateral play. This arrangement

is necessary on account of the fifth central axle, whose bearings have no lateral play in the main underframe.

On each of the two motor-shafts are keyed a pair of cascade motors, the high and low tension motors side by side on the same shaft, and enclosed in one casing.

The tractive force of the locomotive (measured at the rail or wheel-tyre) is 6 tons when the second motor reaches its synchronous speed, that is, about 30 kilometres per hour travelling speed; and it is reduced to $3\frac{1}{2}$ tons when 65 kilometres per hour travelling speed is reached. The motors have, however, 100 per cent. overload capacity, and can without injury exert double these tractive forces.

20. It is useful to consider the comparative advantages of high-tension alternating and low-tension direct current for the purposes of main-line traction.

For long-distance transmission of large powers no one advocates low tension nowadays. The cost of the large copper sections puts this out of the question. Thus the feeders to an extensive system of heavy traffic tramways or urban railways must necessarily be worked at 12,000, 20,000, or 30,000 volts. As this tension cannot be utilized without at least downward, nor always without both upward and downward, transformations of tension, the current in these feeders is necessarily alternating. If alternating current be used in the trolley lines and the car motors, only static transformers are needed. These, having no commutators, collecting-rings, or moving parts, are comparatively cheap in construction per kilowatt; it is comparatively easy to secure perfect and thoroughly reliable insulation in every detail; and they require no attention while in full work. They are locked up in a cellar or small building and left alone; they automatically regulate their activity to the demands made upon them. Only an occasional visit from the man in charge of the line is needed to see that all goes well.

If continuous current is to be used on the trolley line, the feeder tension must in the first place be transformed in a static transformer to such low tension as is usable in a running motor, and the low-tension alternating current so obtained drives a motor which drives a dynamo generating continuous current; that is to say, the transformation has to be completed in a rotary converter.

This rotary converter in the transforming station, although it may not need constant watching, still needs many times more supervision, and thus involves many times more cost in wages, lubricant, cleaning, and repairs than does the simple static transformer. Besides this, we have in the sub-station three losses of efficiency in place of one—one in the static transformer, one in the motor part, and one in the dynamo part of the converter.

Moreover, a static transformer can take for a comparatively long

time, and without overheating or other injury, a much greater overload than can a rotary converter, which is unable to deal with more than 50 per cent. overload. This is not of such paramount importance when the traffic makes a very steady demand on each substation, as in city tramways and dense urban railway works; but it becomes of fundamental and dominating importance as soon as one attempts to solve the problem of general railway traffic with long distances between the stations and long intervals between the trains. Because here the maximum power required from any one sub-station bears a much larger ratio to the average, and the contrast between maximum and minimum power is still more striking.

Now, if one uses continuous current, the only way to surmount this difficulty is either to make the transformer plant in the substation very large, thereby incurring such large cost as makes electric traction impossible, or else to insert large accumulator batteries. The permissible overload in a static transformer depends only on the heating, and thus the rated maximum power needs to be greater than the average only in the ratio of the square root of mean square of the currents to the algebraic mean of the same.

With alternate-current motors very much higher tension can be used than in continuous-current motors. The first result of this is that each sub-station may economically feed a much longer stretch of line, that is, the stations are placed further apart. The cost of the transforming stations bears, of course, a considerable proportion to the whole, and the fewer of them required the better; but beyond this it is easy to see that the longer the length fed from one station, the steadier is the load upon the transformer, the lower the ratio of maximum to average power taken; or otherwise expressed, the higher is the load factor of the station.

A still more direct advantage gained from the use of high tension in the trolley wires is the reduction of the current and the consequent reduction of the section and of the weight of copper used per mile. For the same loss of energy per mile, the section must be proportioned to the square of the current. The current needed for the same horse-power with 700-volt continuous current is over three times as much as is needed with 3000-volt 3-phase current, so that the copper section is ten times as much. Inversely, if one uses the same section in both cases, no more loss than occurs in one mile with continuous current will be incurred in ten miles of transmission by the 3-phase current. Thus, the two $\frac{5}{16}$-inch trolley wires used for the 3000-volt 3-phase current at Valtellina cost £130 per mile, while for the same horse-power transmitted by 700-volt continuous current with the same energy loss, the cost of a copper conductor would be £1300 per mile. A steel rail of the same conductivity as this copper would weigh about 124 lb. per yard, and would cost about £900 per mile.

The reduction of the current effected by the high voltage also reduces in the same proportion the loss of voltage in the return earth rails. With alternating current no electrolysis in water and gas pipes arises from the earth returns.

It is said that no more than about 300 ampères can be collected by a trolley from an overhead line without using a mechanical pressure so great as to produce injurious swinging of the wires. Thus the horse-power that can be so collected by continuous current varies from 240 at 600 volts to 2000 at 5000 volts. At 3000 volts 1200 horse-power could be obtained by continuous current, and over 1500 horse-power by alternating current with ordinary average values of self-induction and power-factor. This horse-power being sufficient for a train in a full railway service of general character, the voltage of 3000 was selected by Messrs. Ganz and Co. as the best standard for the new system. In pushing the voltage higher than this, practical difficulties begin to appear in respect of the insulation of the motor windings, and the cost of securing absolute safety of life to the employés and to the public rises rapidly.

As regards danger to life from high tension, it is incorrect to say that this does not exist up to a definite limit, and does exist above that limit. Recent researches, and especially those of Professor H. F. Weber and of Mr. Trotter of our Board of Trade, indicate that the damage done by a shock depends more upon the condition of the recipient—the robustness or weakness of his nervous system, upon the dryness or dampness of his skin, upon the particular manner in which contact has been made, and upon many other changeable circumstances—than upon the voltage. The fact that the precautionary safety appliances adopted with high tension are designed and executed with infinitely greater care and thoroughness than in the use of low tension is in itself so substantial a guarantee of safety as even to make high preferable to low tension in regard to this one point of safety. The one absolute safeguard—there is no other thoroughly reliable method—is to make good earth contact to all the parts that can be touched by living beings. Provided the conductive passage to earth from any such part is thoroughly free and ample, that part can in no circumstances be raised above earth-potential more than a very few volts. Thus the whole framing and roof of the Ganz cars are of iron in good contact with all the wheels, while the eight wheels are in contact with the steel rails. All the leads carrying high-tension current are everywhere enclosed in rigid and practically unbreakable iron tubes and boxes, every one of which is in permanent riveted or bolted contact with the frame. These leads are, of course, elaborately insulated from these enclosing iron casings; but if this insulation were broken down in any part, partially or completely, even then no danger to persons would

arise. The result of such breakdown, if partial, is leakage to earth and loss of energy, and, if complete, it is the establishment of a short-circuit, which at once burns out the fuses. In either case no person is harmed. The fuses are burnt out in order to protect the machinery, not for the protection of persons. The danger to persons thus never can arise *directly*. It can only arise indirectly through fire caused by the overheating of the motor windings, and this overheating, provided these windings be sufficiently insulated, is *less probable* the smaller the current; that is, the *higher is the voltage.* The high voltage exists only in the stator windings of these induction motors, and perfectly reliable high-grade insulation is very easy in fixed parts as compared with its practicability in moving parts.

21. This Ganz high-tension 3-phase induction-motor system has been taken up in this country by Messrs. Bruce, Peebles and Co., of Edinburgh, whose tramway-traction motors have already received notice in this volume. They are engaged upon two railways upon the Ganz system. The first is a 3-phase railway 18 miles in length in North Wales, and the second an inter-urban line in Canada.

The North Wales scheme is part of an installation being carried out for the North Wales Power Co. This will be of special interest as the first hydro-electric power distribution scheme in the United Kingdom. It is called the "Portmadoc, Beddgelert, and South Snowdon Railway." The water power is obtained from Loch Llydaw on the lower summit of Snowdon, with 1200 feet head. Pelton water-wheels will be employed in the power-house to drive four Peebles 1500-kilowatt 10,000-volt 3-phase alternators. The current is utilized for two purposes, one being to supply electric power for lighting various districts in the neighbourhood, and also for industrial use in numerous quarries, etc.; the other for the driving of the electric railway. The power-house is situated at Portmadoc, and the railway runs inland, rising rapidly into the mountain district, eventually reaching what is expected to become one of the best-known sanitoria in this country. The railway is of narrow 2-feet gauge, and, as the gradients are severe, some of them 1 in 40, locomotives of 250 horse-power are required. As motors of such high power cannot be fitted in between the wheels of narrow-gauge trucks, they are arranged with vertical spindles, and drive the locomotive axles by bevel gearing.

The locomotive carries one motor only of 150 rated horse-power, but capable of 100 per cent. overload. One locomotive will draw a train up a gradient of 1 in 40 at 18 miles per hour. On the steeper part of the route either two locomotives per train or half-length trains will be used.

The electric railway will be 3-phase throughout, there being two overhead lines with the rails used as the third conductor. As the

railway feeders supply numerous quarries on the line of route, the advantage of one system for both purposes is obvious. Both passenger and goods traffic will be handled on this line. At various sub-stations let-down static transformers reduce the voltage from 10,000 to 650 volts, and this is the voltage along the trolley-wires at which the current is collected to be led into the motors on the train.

22. The Canadian scheme comprises a 3-phase railway line some 30 miles in length, commencing at the city of London in the province of Ontario, Canada, and running thence to Port Stanley on Lake Erie. The initial power-house capacity will be 1000 horse-power, and the motors for the rolling-stock are of very interesting design, the object being to enable the large inter-urban cars to run on the street railway track on continuous current through the city of London, and also on a 3-phase track with two overhead lines and the rails as third conductor outside the town limits. The motors thus operate either on continuous or 3-phase current, the 3-phase voltage being 1000 and continuous 500. The motor is not dissimilar to an ordinary traction motor, having a commutator at one end and slip rings at the other end of the armature. The field-winding is not distributed as in the majority of alternating current motors, but is on pole-pieces as in continuous-current machines. Each car on this line will be fitted with two 150-horse-power motors, and high speeds will be attained. These two 150-horse-power duplex motors will be geared to the driving-axles. No locomotives are to be used. The motor-coach will be of the double-bogie type with both motors on one bogie.

CHAPTER XII

SWISS THREE-PHASE RAILWAYS AND ZOSSEN HIGH-SPEED TRIALS

1. Lugano Tramway—2. Advantages of Low-tension 3-phase Traction—3. Zermatt-Gornergrat Rack Railway—4. Ditto, Track, Power-station, Transmission, and Locomotives—5. Jungfrau Tunnel Rack Railway—6. Ditto, Tunnel Construction—7. Ditto, Power-station, Transmission—8. Ditto, Track—9. Ditto, Passenger Coach—10. Ditto, Locomotives Nos. 1 and 2—11. Ditto, Locomotive No. 6—12. Thun-Burgdorf Railway—13. Ditto, Power-station—14. High-tension Transmission—15. Ditto, Transforming Sub-stations—16. Ditto, Contact Line—17. Rail Return—18. Ditto, Motor-coaches—19. Ditto, Locomotives—20. Ditto, Electric and Speed Measurements—21. Ditto, Costs—22. Other Swiss 3 phase Railways—23. Swiss Direct-current Traction-work—24. Swiss 3-phase Generators—25. Low-tension 3-phase Energy for Tramways—26. Obstacles to High Speed—27. Advantages of Electric over Steam Traction for High Speed—28. Zossen High-speed Trials. A.E.G. Motor-coaches—29. Ditto, the Line Transmission and Bow-collectors—30. Ditto, Maximum Measured Results—31. Ditto, Average Measured Results—32. Siemens and Halske New Locomotive—33. Single-phase Traction.

1. NOWHERE has there been seen greater enterprise nor more rapid development, in recent years, in polyphase electric work, and in particular polyphase electric railways, than in Switzerland. This has been very largely due to the energy and skill in adapting a variety of means to various needs of the firm Brown, Boveri and Co., whose works are in Baden. This company has done a great deal of electric work of all kinds in most of the countries of Europe, and we have already mentioned their great hydraulic-turbine power-station at Paderno, 20 miles outside Milan, where they generate 15,000 volts direct in the armatures of their alternators. In Milan itself also they have laid down three 3-phase 1050-horse-power generators driven by twin compound steam-engines, both these installations being those of the "Società Generale Italiana Edison di Elettricità," and most of the power being used for direct-current tramway traction.

The earliest application of 3-phase induction motors to traction purposes (outside the sphere of small mine installations) was made by Brown, Boveri and Co., on the tramways in and around the town of Lugano. This work, which has already been referred to in

Chapter X., was finished, and successful trial runs made, in December, 1895. Although only 4·9 kilometres route-length, and therefore of small magnitude, it will always be of historic interest as the first materialization of a system which is likely to have great development in the near future. There are three short 6-per-cent. gradients and several long 3-per-cent. grades. The power is obtained from a 300-horse-power water-turbine, 12 kilometres distant from Lugano, this driving, at 600 revolutions per minute by direct elastic coupling, a 3-phase generator yielding 5000 volts at 40 frequency. A special feature of this dynamo is that, while the armature is exterior and fixed as is usual, the windings of the magnetic field are also fixed and stationary, only the iron cores and pole-pieces being rotated. Two sets of radially placed pole-pieces (four in each set) rotate in parallel planes, between which the windings are arranged, and each pole in each set stands opposite the gap between two poles in the other set. This arrangement avoids the necessity of having separate armature windings for the two sections in which the armature of this style of machine is built.

The 5000-volt current is brought down to a single transformer sub-station by three overhead wires 5 millimetres in diameter. Here it is transformed to 400-volt 3-phase, and this is taken along the route by two 6-millimetres overhead wires and the track-rails as the third conductor. The overhead wires are 250 millimetres apart, and the current is collected by two trolley-wheels on separate poles, one mounted about 1 metre behind the other. The cars are small ones for 24 seats, and each is driven by one 20-horse-power 3-phase motor geared to the driving-axle in the ratio 4 to 1. A speed of 15 kilometres per hour is attained.

2. The arguments in favour of 3-phase tramways, even when low tension is used, are thus stated by Messrs. Brown, Boveri and Co. The weight of the two wires is only some 35 per cent. greater than that needed for the direct-current single wire, so that there is practically no difference in the size of side-pole and span-wire required. Complication at crossings and switches is avoided by taking one of the two wires past the crossing underground, it being well known that 3-phase induction motors, when once started, will work with one of the three-phases suppressed or interrupted, so that the car is driven past the crossing in spite of the absence of one of the overhead wires. This same characteristic of 3-phase motors makes the use of two wires a guarantee against stoppage from breakdown of one of them; while also there is substantial reduction of sparking from the practical impossibility of both trolley-wheels jumping from the wire at the same instant. Such jumps occur under the insulator suspensions and at splicings of the wire, and these are not passed by the two trolleys simultaneously, because one runs a metre behind the

other. Of most importance, however, are the small loss in the sub-station transformation and the absence of wages of attendance on, and lubrication of, running machinery; the greater overload capacity of the sub-station plant; the absence of the commutator from the

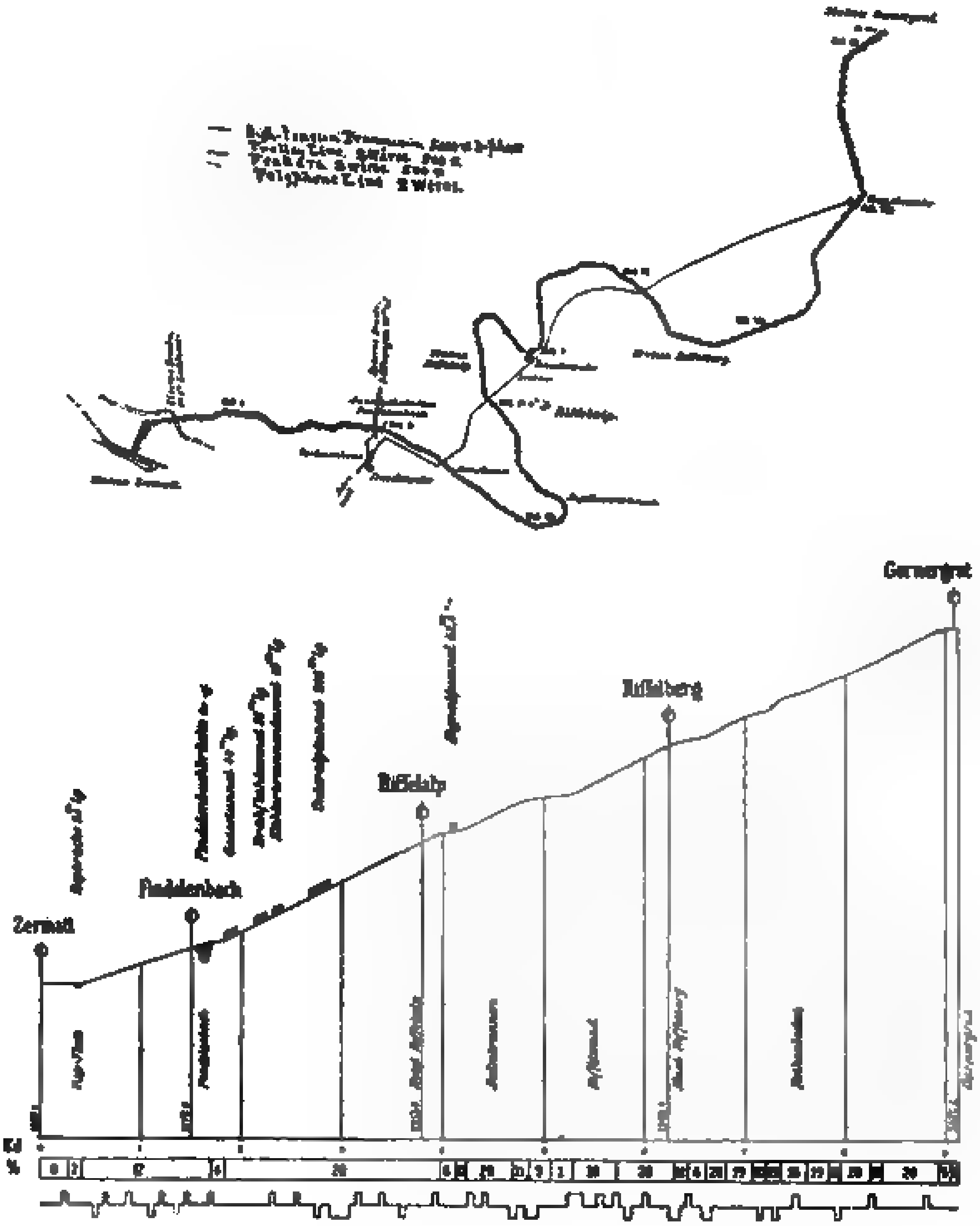


FIG. 268.—Plan and Section of Zermatt-Gornergrat 3-phase Rack Railway.

car-motor; the low-tension rheostat regulation of the motor upon the rotor circuit, with complete absence of dangerous excess current in starting; nearly constant full-speed running in spite of great variation of resistance; and recuperation of energy on descending gradients.

The last characteristic is of special value on mountain railways, the descending trains supplying so much energy to the line as to very materially reduce the central station maximum output that would be necessary on any other system.

3. In November, 1897, the first trial trips were successfully made upon the electric rack railway climbing from Zermatt to Gornergrat on the edge of the great Gorner glacier on the northern slope of Monte Rosa. Regular running upon it began in the following summer. Fig. 288 gives a plan and profile of this line. It starts at 1607 metres above sea-level, and climbs a vertical height of 1413 metres in 9·1 kilometres horizontal length. The ruling gradient is thus 156 per 1000. Throughout six stretches the gradient is 200 per 1000, or 1 in 5, and on four other stretches it is 190 per 1000. Including the two termini, there are five stations. Previous to this date only one other railway had reached a higher level, namely, that to Pikes Peak in Colerado, which is 4260 metres over sea-level. Including 5-minutes' stop at each station, the whole ascent is made in 1 hour 30 minutes with a train seated for 110 persons. The work in the tunnels was continued throughout the winter, 150 men being lodged and provisioned through the winter at 2000 metres, or 6560 feet, above sea-level. The summer out-door working season lasts for three to four months only, and during this 1100 men were employed to push on the construction of the road and bridges. Frequently 20 feet depth of snow had to be cleared to permit progress of the work. There are many bridges, and one of very remarkable construction over the Findelenbach. This is a steel lattice girder extending over three spans, each of 28 metres span, the whole at the uniform gradient of 1 in 8, and the two masonry piers between the spans being 49 metres high. The down-thrust on the abutment at the lower end must be very considerable and subject to hammer-blow variation when a train, especially a descending train, comes upon the bridge; but these thrusts are taken by a solid rock foundation.

The Italian navvies from Lombardy employed were unaffected by the rare air up to an altitude of over 2200 metres; but at between 2700 and 3000 metres "mountain-sickness" increasingly affected them. This is a sort of fever creating pain in the head and throat which deprives the patient of working energy. He recovers with a few days rest at lower levels, but it returns if he goes back to work at the high levels; and the illness is more difficult to combat in the colder autumn weather than in summer. Above the 3000 metres only acclimatized native labourers could be employed.

4. The gauge of the railway is 1 metre, with Vignole track-rails 4 inches deep and weighing 50 lbs. per yard bolted to transverse steel sleepers spaced 1 metre apart normally, but only ½ metre apart at

the rail joints. The rack comes midway between these running-rails. Fig. 289 shows the section of the track with the steel sleeper 1·8 metre long. Fig. 290 gives section and side view of the rack. This consists of a solid ⊥-section chair, bolted to the sleeper, and two parallel flat steel rack-rails, each $\frac{3}{4}$ inch thick, bolted by two bolts to each chair. The teeth are of 60 millimetres ($2\frac{3}{8}$ inches) pitch, and have straight-line flanks. The two rails are placed so that the teeth on one lie opposite the gaps in the other. Two independent spur-wheels driven by the motors on the locomotive engage with the two racks, so that the one is engaged to full depth while the tooth of the other is coming into contact or leaving contact. The greatest thrust brought upon a tooth is 6 tons. About 160 horse-power is required for each train at the driving pitch-circle, and for this two 90 horse-power Brown-Boveri 3-phase motors are carried on each locomotive. The line voltage is 500 with 40 periods per second and 800 revolutions per minute in the motors. With $\cos \phi = 0{\cdot}88$, the maximum driving moment yielded by the two motors is 160 metre-kilograms.

The power is obtained from hydraulic Girard turbines driven by

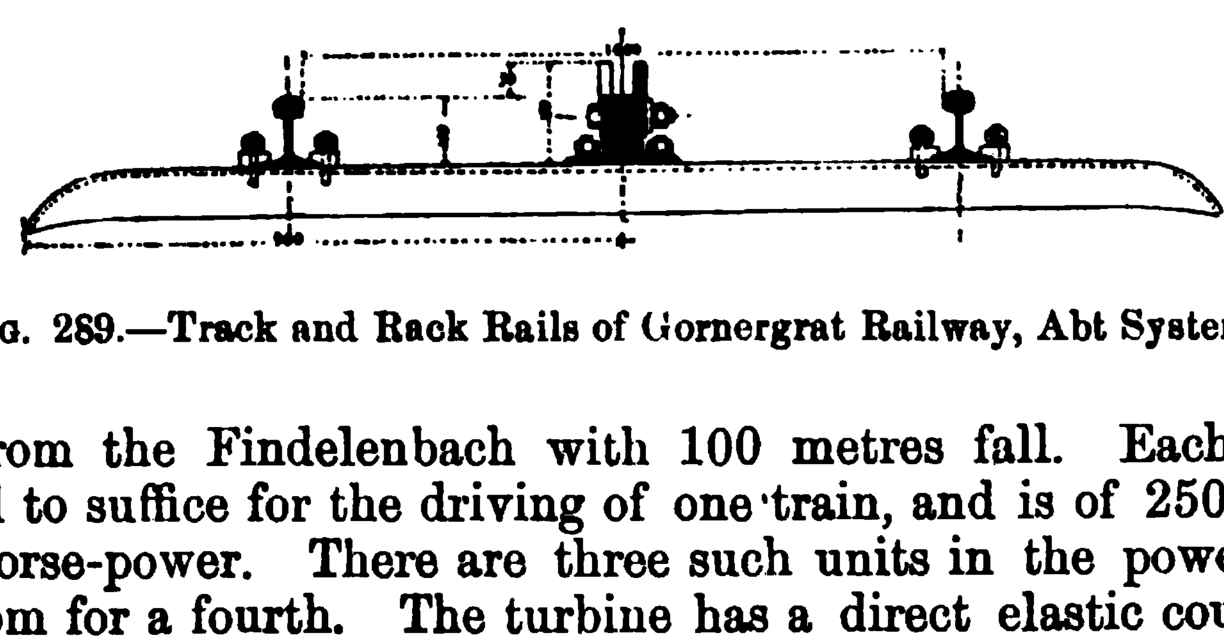


FIG. 289.—Track and Rack Rails of Gornergrat Railway, Abt System.

water from the Findelenbach with 100 metres fall. Each unit is intended to suffice for the driving of one train, and is of 250 turbine brake horse-power. There are three such units in the power-house, with room for a fourth. The turbine has a direct elastic coupling to the alternator, both running at 400 revolutions per minute, and this giving 40 periods per second, the alternators being 12-pole machines. The generated voltage is 5400. With regulation by centrifugal speed governors controlling a servomotor on the turbine, tests gave only 1 per cent. variation of speed between no and full load, and in the regular working of the trains 2 per cent. is the maximum variation observed.

The high-tension transmission is by three overhead wires, each $5\frac{1}{2}$ millimetres in diameter to the nearer sub-station and 4 millimetres in diameter beyond this to the distant station one kilometre from Gornergrat. This high-tension line runs across country, not following the curves of the track, as seen in Fig. 288.

There are three transforming stations, including that close to the power-station; and, at each, 180-horse-power transforming capacity is installed in the form of six single-phase 30-horse-power static

transformers, that is, two sets of 90-horse-power 3-phase ditto. From these two 8-millimetre wires take the energy to the trolley-line, the third phase passing by the earth and rails. The two trolley-wires are also 8 millimetres thick, and are supported by transverse steel-wire suspensions from 2-pole timber frames spaced 25 metres apart. The same poles carry the feeders and the telephone lines. The trolley-wires are 400 millimetres apart.

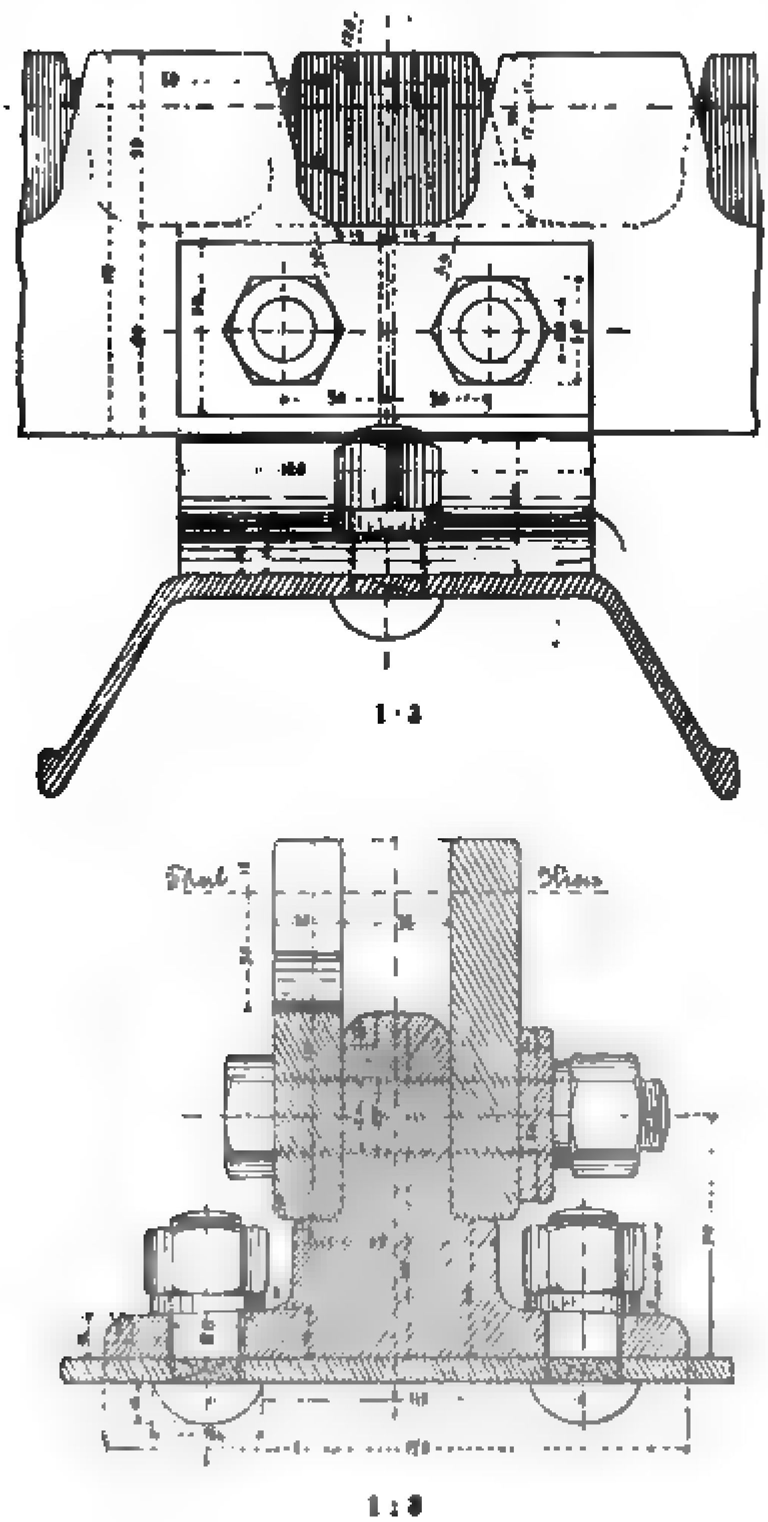


Fig. 290.—Abt Railway Double Rack.

The motors on the locomotive are double-geared to the driving spur-wheels, the gear-ratio being 1 to 12, and the synchronous motor-speed corresponding to 7 kilometres per hour travelling speed. They are 6-pole machines, and their synchronous speed is 800 revolutions per minute. Both hand and electrical brakes are applied, the latter being under the driver's control, but being also automatically tripped into action if the current supply is, from any cause whatever, interrupted, as also whenever a specified speed limit is exceeded. When running downhill above synchronous speed, the motors act as generators and deliver energy to the overhead line.

5. A still more wonderful Swiss mountain railway is that to the top of the Jungfrau. Part of it was finished and opened for traffic in 1899, and it is not yet complete. It also has been electrically

equipped by Brown, Boveri and Co. It was first projected by Herr Adolph Guyer-Zeller, the president of one of the Swiss railway companies; but, unfortunately, no part of it was in active work before the death of the originator of this boldest of all railway schemes. The plan and profile are seen in Figs. 291 and 292. The line starts from the Little Scheidegg station on the railway from Lauterbrunner over the Wengernalp to Grindelwald. This is at an elevation of 2064 metres above sea-level, and the railway climbs to 4093 metres above sea-level in a horizontal length of 12½ kilometres. The ruling gradient is thus 165 per 1000. The maximum gradients are 215, 241, 250,

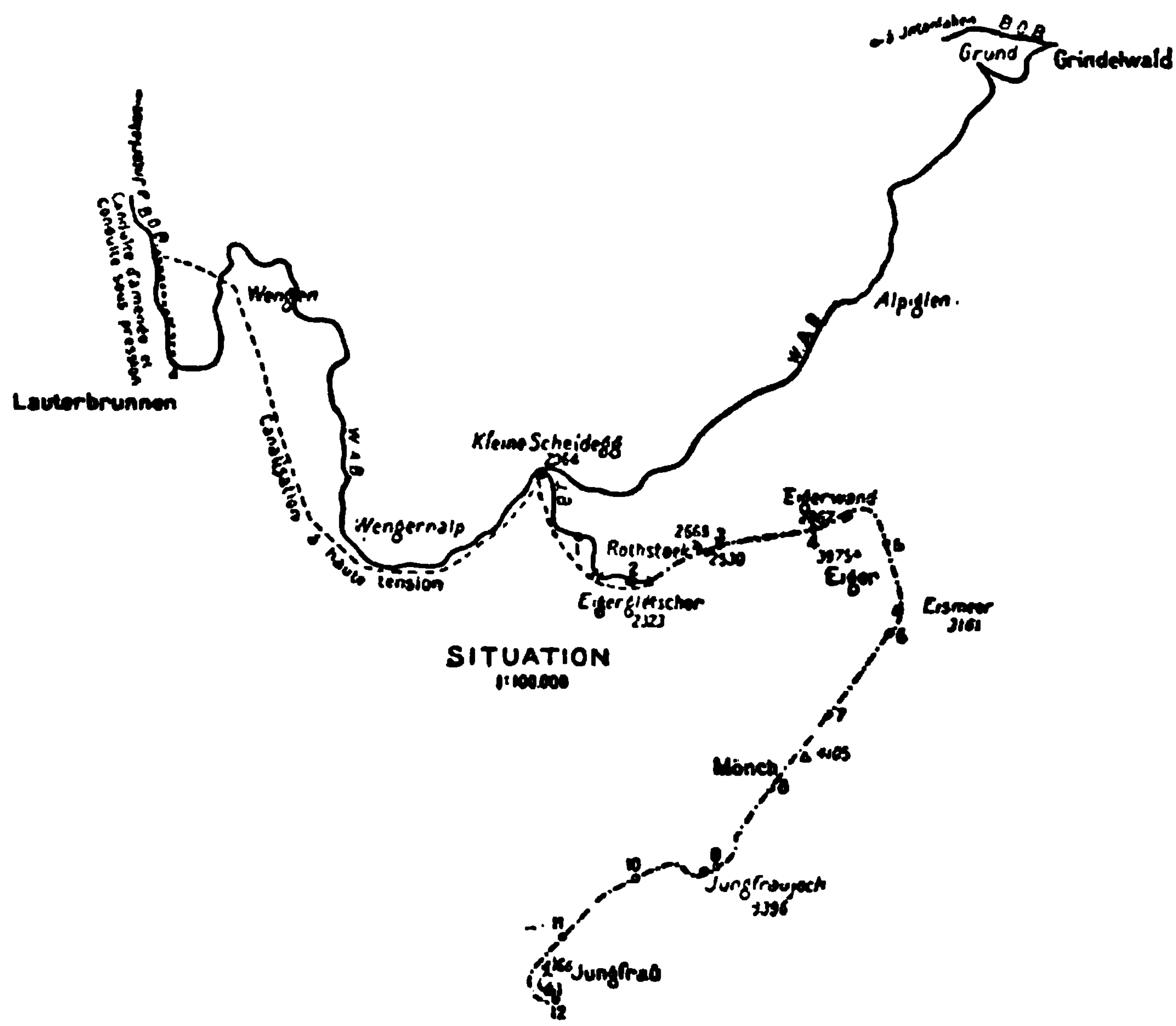


FIG. 291.—Plan of Jungfrau Rack Railway.

250, 250 and 250 per 1000; there being four stretches at 1 in 4, the last of which has a length of 3 kilometres.

The railway does not lead into the open at its upper end; but it is proposed to drill a vertical shaft 73 metres = 240 feet high, through which, by an electrically driven lift, passengers will be brought to the extreme summit of this the grandest and most beautiful of all Swiss mountains. The line runs in the open for a length of 2 kilometres to the first station close to the Eigergletscher. It then pursues the whole of its way in tunnel drilled and blasted out of the solid rock. The second station is 1 kilometre from the first, and

debouches upon a gallery overlooking Rothstock gorge. Another $1\frac{1}{2}$ kilometre of tunnel brings it to the Eigerwand station, and another stretch of about 1 kilometre to the Eismeer station. From the plan (Fig. 291) it may be understood that these different stations, from all of which there are exits to the mountain sides, give entirely different views—over, one might almost say, different portions of Switzerland.

6. It is interesting to note that photographic surveying gave great assistance in the planning and setting out of this railway, much of the route being quite inaccessible for any processes of direct surface survey.

The boring is chiefly through tough, hard limestone, on which

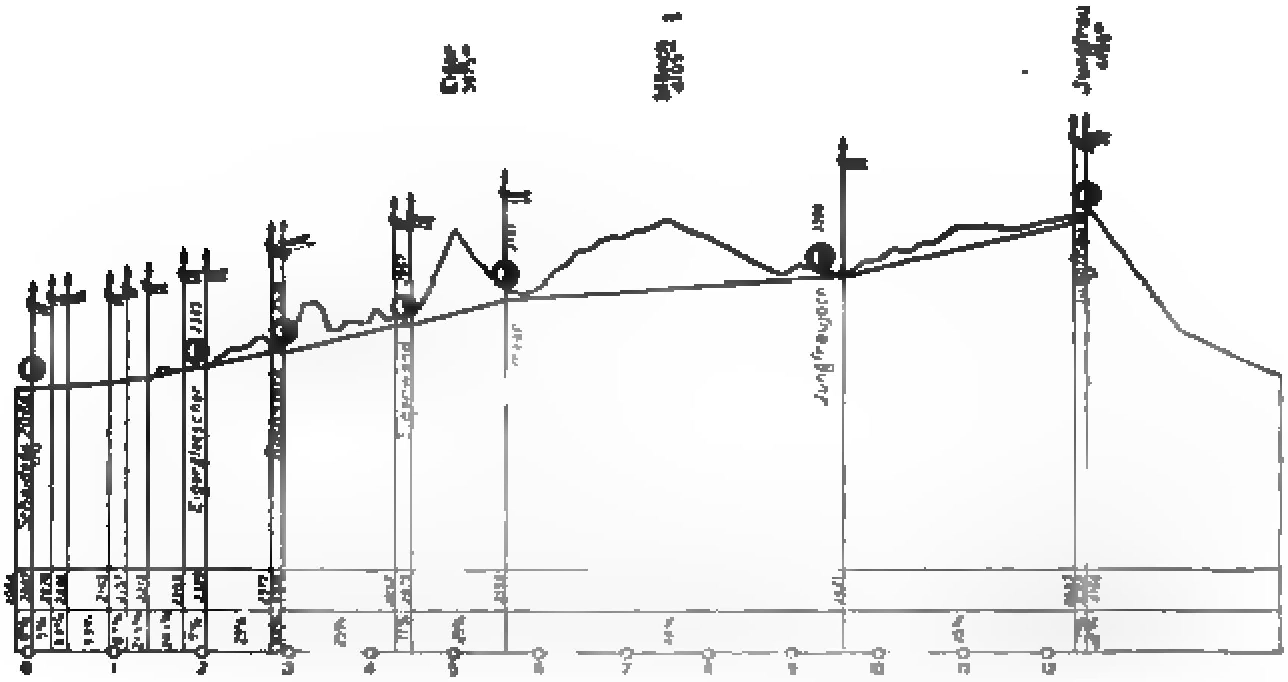


FIG. 292.—Profile of Jungfrau Rack Railway.

hardened drills were found to be of little use in consequence of excessive wear and breakage. Soft steel impact or percussive drills, driven by Thomson-Houston 3-phase motors, were found to be efficient tools for the purpose. They give 380 blows per minute, and drill a $1\frac{1}{2}$-inch hole $3\frac{1}{2}$ feet deep. Four of these, mounted in pairs upon radial standards, are employed on one face. Twelve to fourteen holes are bored in the face, which is then blasted with dynamite-gelatine. Each borer consumes about 5 horse-power electric energy.

The upper half of the tunnel, which is 4·35 metres high by 3·7 metres wide, is in semi-circular arch form, and the rock is so sound and dense that practically no masonry or other lining has been needed. The upper half alone is cut in the first place as far as the next station ahead, where, through the opening to the mountain side,

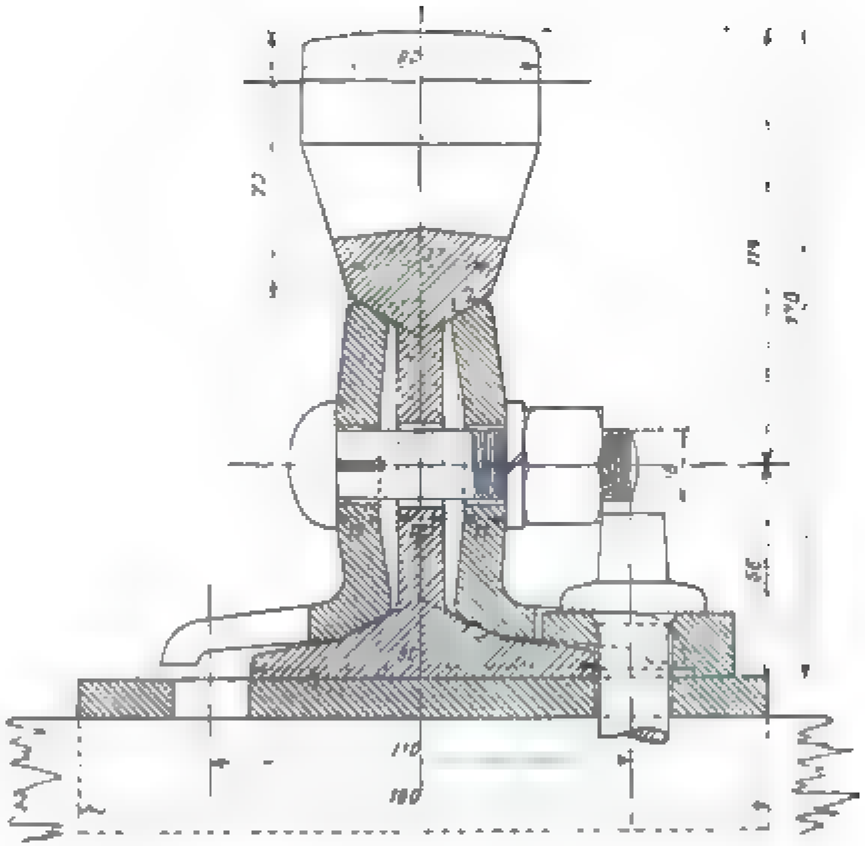


Fig. 293.—Cross Section.

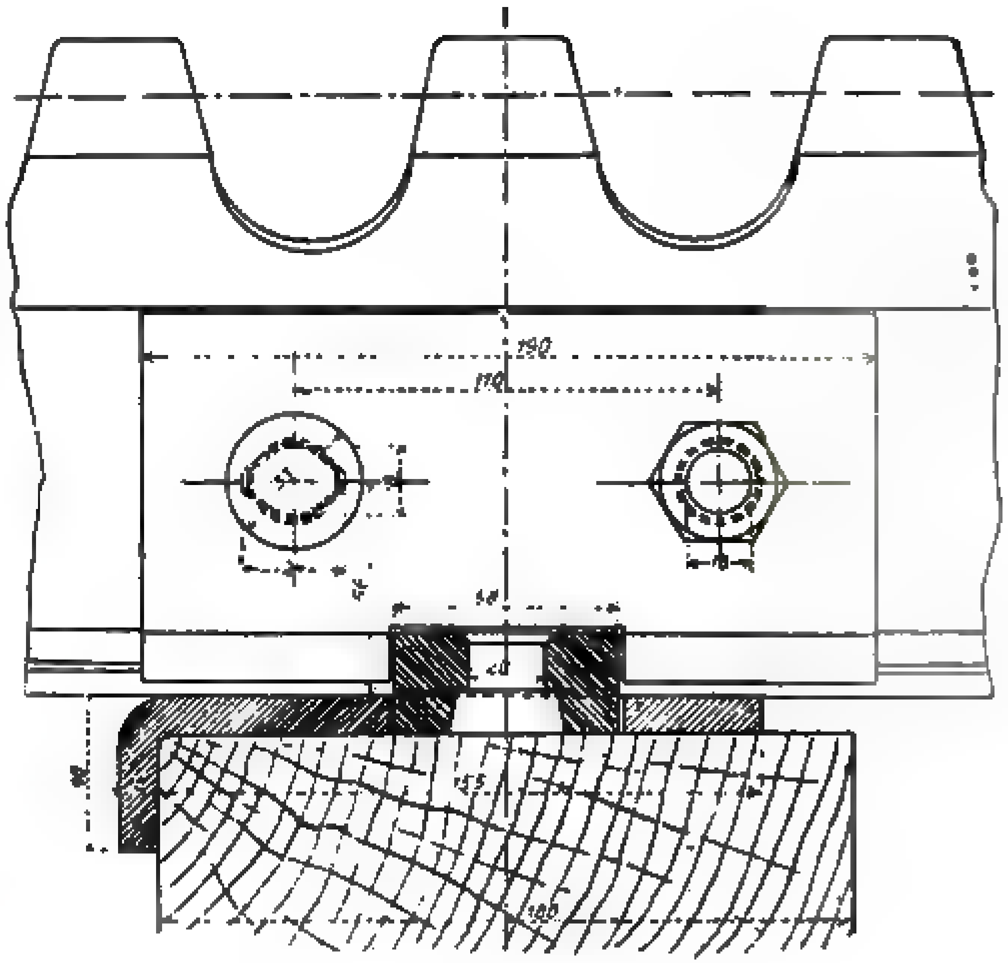


Fig. 294.—Side Elevation.

Strub Rack Rail.

the excavated material for the rest of the cutting is got rid of. This procedure also facilitates, and lessens the expense of, the ventilation of the tunnel during the progress of the work, the progress to a new ventilating opening being doubly rapid.

7. The power-station is at Lauterbrunnen in the bottom of the valley, and the power is obtained by turbines from the water of the Weisse Lutschine, led to the power-house by riveted steel-plate flumes 1·8 metre in diameter with a fall of 40·8 metres. Over 2500 horse-power are available. Two 500-horse-power Girard turbines (Rieter and Co.), two 800-horse-power Francis turbines (Escher, Wyss and Co.), and two auxiliary 25-horse-power turbines to drive the exciters and other miscellaneous work, have been laid down.

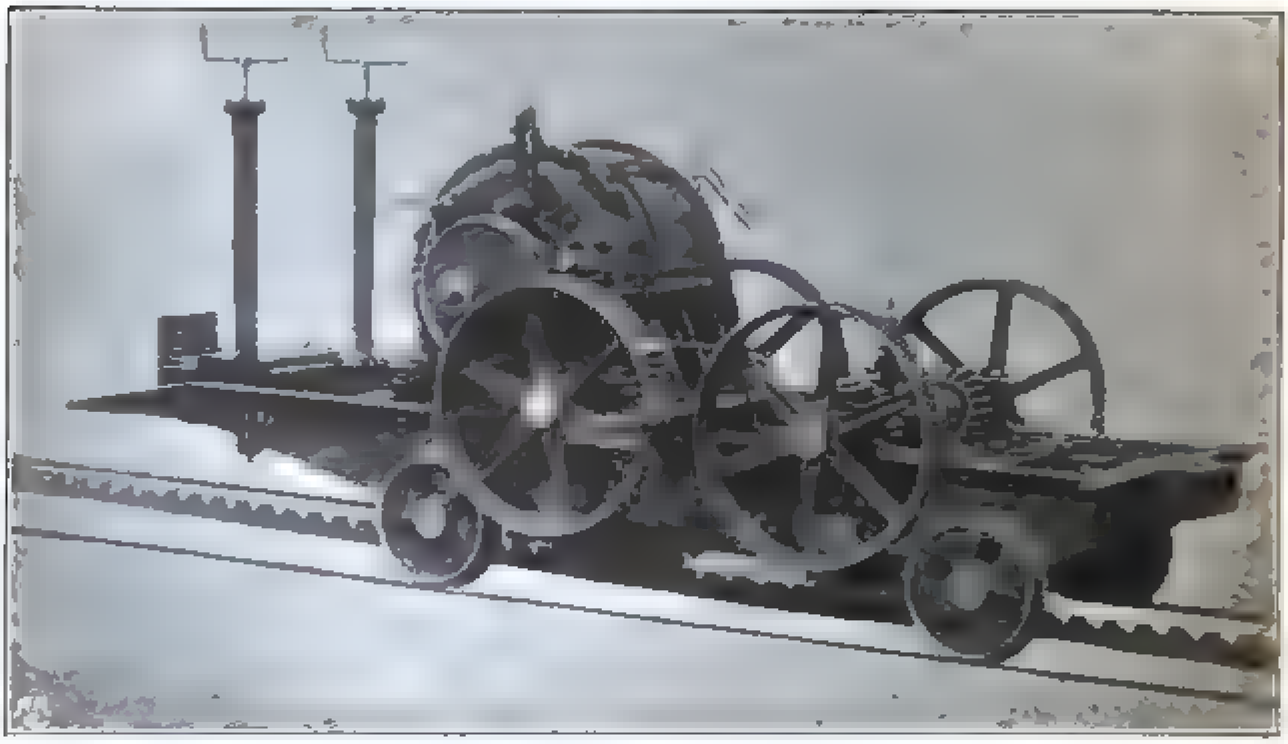


FIG. 295.—Locomotive on Jungfrau Railway, Truck, Motor, and Gearing.

Four Brown-Boveri 3-phase 7000-volt alternators of corresponding power are driven, direct-coupled, by these turbines. The speed is 380 revolutions per minute and the periodicity 38.

Three overhead 7½-millimetre copper wires on poles of pickled timber carry the high-tension transmission. At each transformer-house there are two 3-phase 200-kilowatt transformers bringing the tension down to about 500 volts.

The two trolley-wires are 9 millimetres in diameter, and are carried by 6-millimetres steel span-wires on 2-pole standards in the open, and on bolts cemented into the rock arch-vault in the tunnels.

8. The track is of 1-metre gauge, and the running-rails are of the same pattern as illustrated in Fig. 289, and weigh 19½ kilograms per

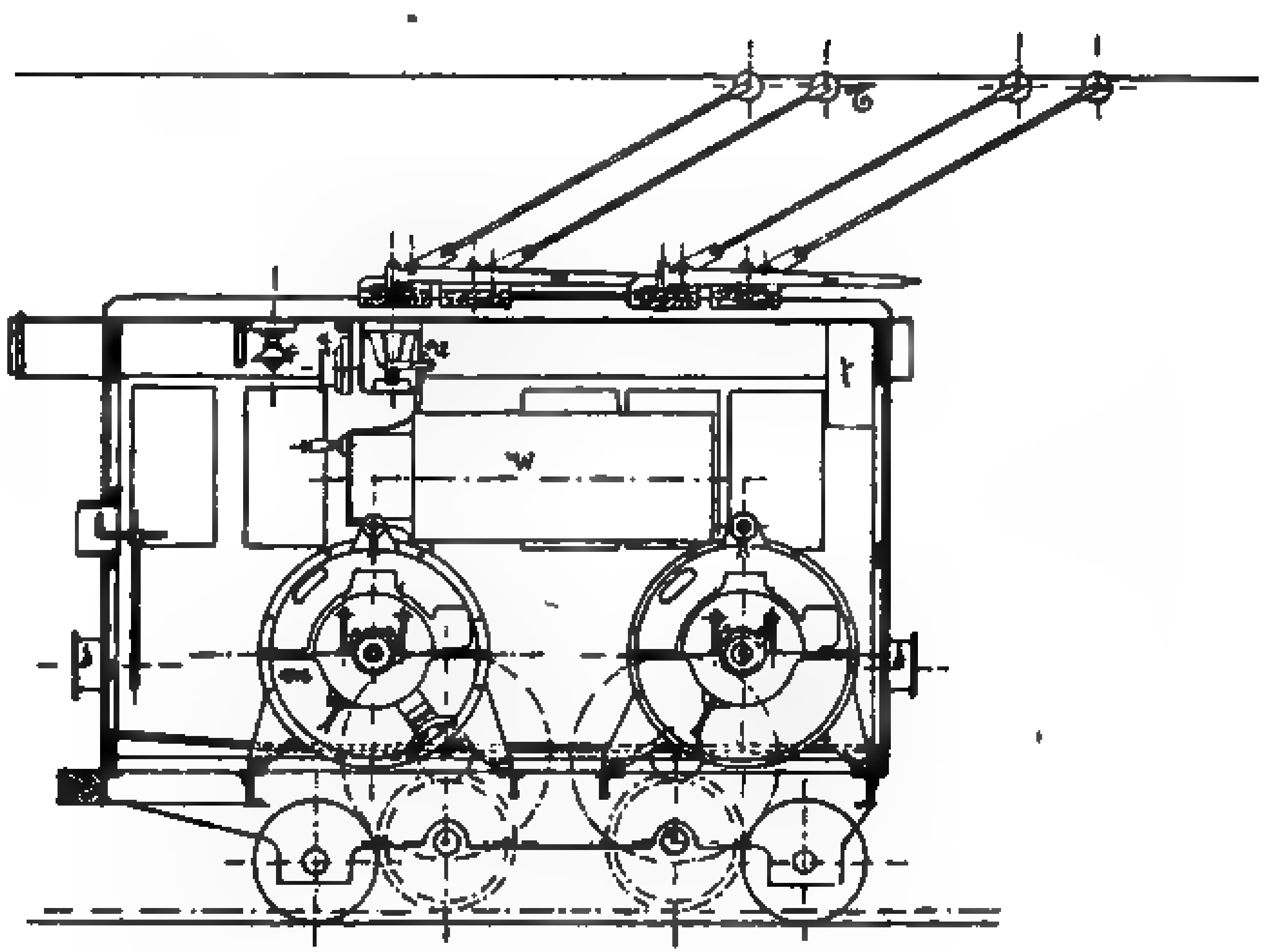


FIG. 296.—Longitudinal Section.

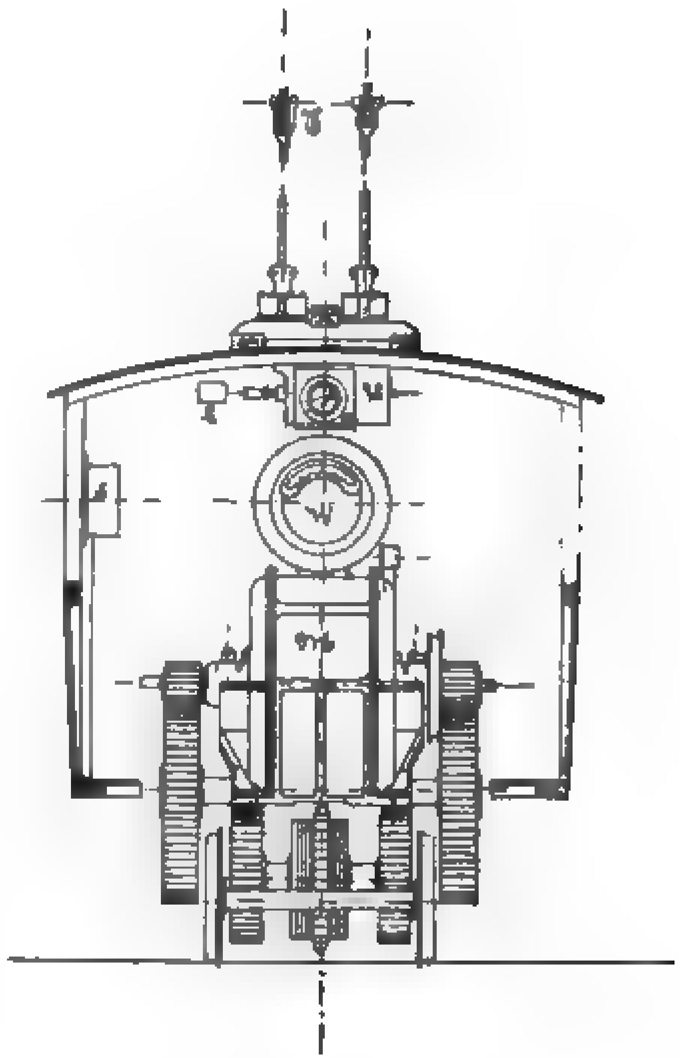


FIG. 297.—Cross Section.

Three-phase Locomotives Nos. 1 and 2 on Jungfrau Rack Railway—Brown-Boveri & Co.

metre. The rack-rails are of the Strub pattern, which is illustrated in Figs. 293 and 294. This is a single rail with a tooth 2½ inches wide and 4 inches pitch. The rail has a 3½-inch base-flange and a web ½ inch thick. The head of the rail at the base of the teeth is 1½ inch thick. Ninety-pound steel sleepers are used for track and rack rails.

9. In ascending, the locomotive pushes the passenger-car in front of it, the coupling between the two including a spring suspension whereby a portion of the weight of the car is thrown upon the front

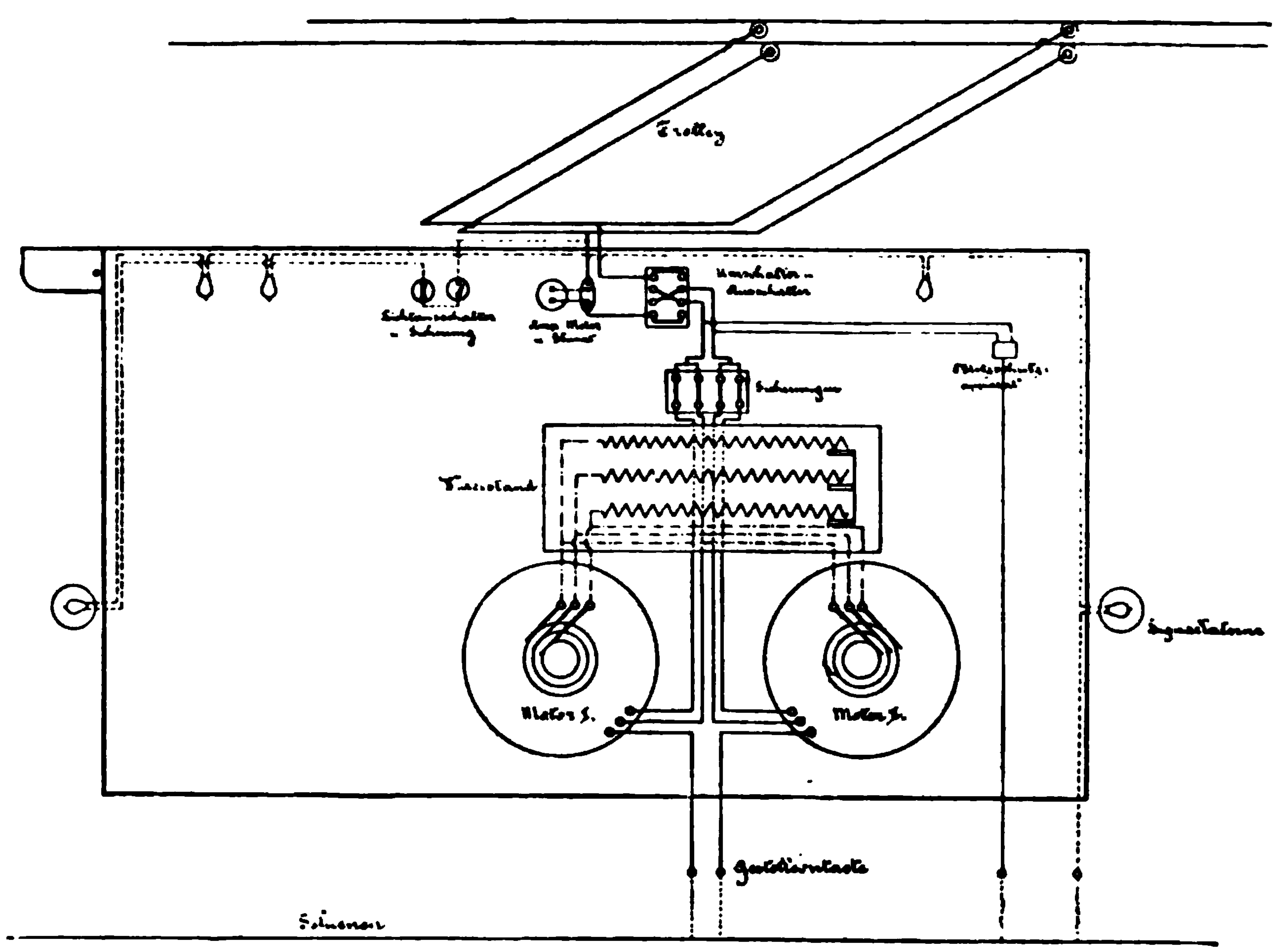


FIG. 298.—Electric Connections of Jungfrau Passenger Locomotive.

end of the locomotive. The car is 7 metres long, and stands 2·85 metres above the rails. It is seated for 40 passengers. A train is made up of either one or two of these cars and one locomotive.

10. Two somewhat different patterns of locomotive have been put on the line. Fig. 295 gives a photographic view of one of these with the cab removed, and Figs. 296 and 297 give its longitudinal and cross sections. Fig. 298 gives the scheme of its electrical connections. It collects current by four trolley-wheels, two for each phase running on each overhead wire.

The locomotive weighs 13·8 tons, and is driven by two 3-phase 500-volt motors, each of 150 rated horse-power. Each of these is double-geared to its driving spur-wheel, the total gear-ratio being 11·65, and each gear being symmetrically duplicated right and left hand. In this gear helical spur-teeth are employed. The normal motor speed is 760 revolutions per minute; and that of the spur-driver, whose pitch diameter is 700 millimetres, is 65 revolutions per minute. The running wheels have 600 millimetres diameter, and the maximum driving-thrust exerted between them and the rack-rail is 9 tons. The steady travelling speed is 8·1 kilometres per hour.

In Figs. 296 and 297 the rheostat resistance is marked W. It is placed longitudinally over the two motors marked M. U is the reversing switch connected with the automatic excess-speed brake; δ is a box containing safety fuses protecting the motors; b contains the lightning protector; t is a transformer for the lighting service.

In travelling downhill, there are in readiness three independent brakes, each capable of stopping the train. Two of these are block-friction brakes acting upon brake-drums on each side of the spur-drivers. The third is an automatic band-brake acting direct upon the motor axles, the bands being tightened by a spring tripped into action by a centrifugal governor when the speed rises above 10 kilometres per hour. This band-brake may be also applied by hand. When a long downhill run is made without current to the motors, the spur-wheel brake-drums are cooled by a water-circulation.

There is also a safety linkage between the track-wheel axles and the spur-driver shaft, which ensures that the latter never rises so high that its teeth disengage from the rack-rail, this being necessary because of the spiral-spring suspension of the truck upon the running-wheel axles.

In downhill running, if the motors be in forward gear they automatically act as generators whenever the synchronous speed is exceeded, the energy thus produced going into the overhead line and assisting in driving the trains travelling uphill, and so, at the same time, relieving the central station of part of its load. In the event of this action going so far (when several trains are simultaneously travelling downhill) as to diminish the central station load to below zero, the excess energy is absorbed by special resistances erected in this station for this purpose.

11. Fig. 299 shows in perspective the later design of more powerful locomotive put upon the line. This has been constructed to assist in the heavy work of construction involved in the upper reaches of the railway; but it will also serve as a passenger locomotive after completion of the line, being capable of drawing a train of two fully loaded coaches. In the construction work, its load is about 10 tons greater than with a single-coach passenger train. It exerts 10 tons

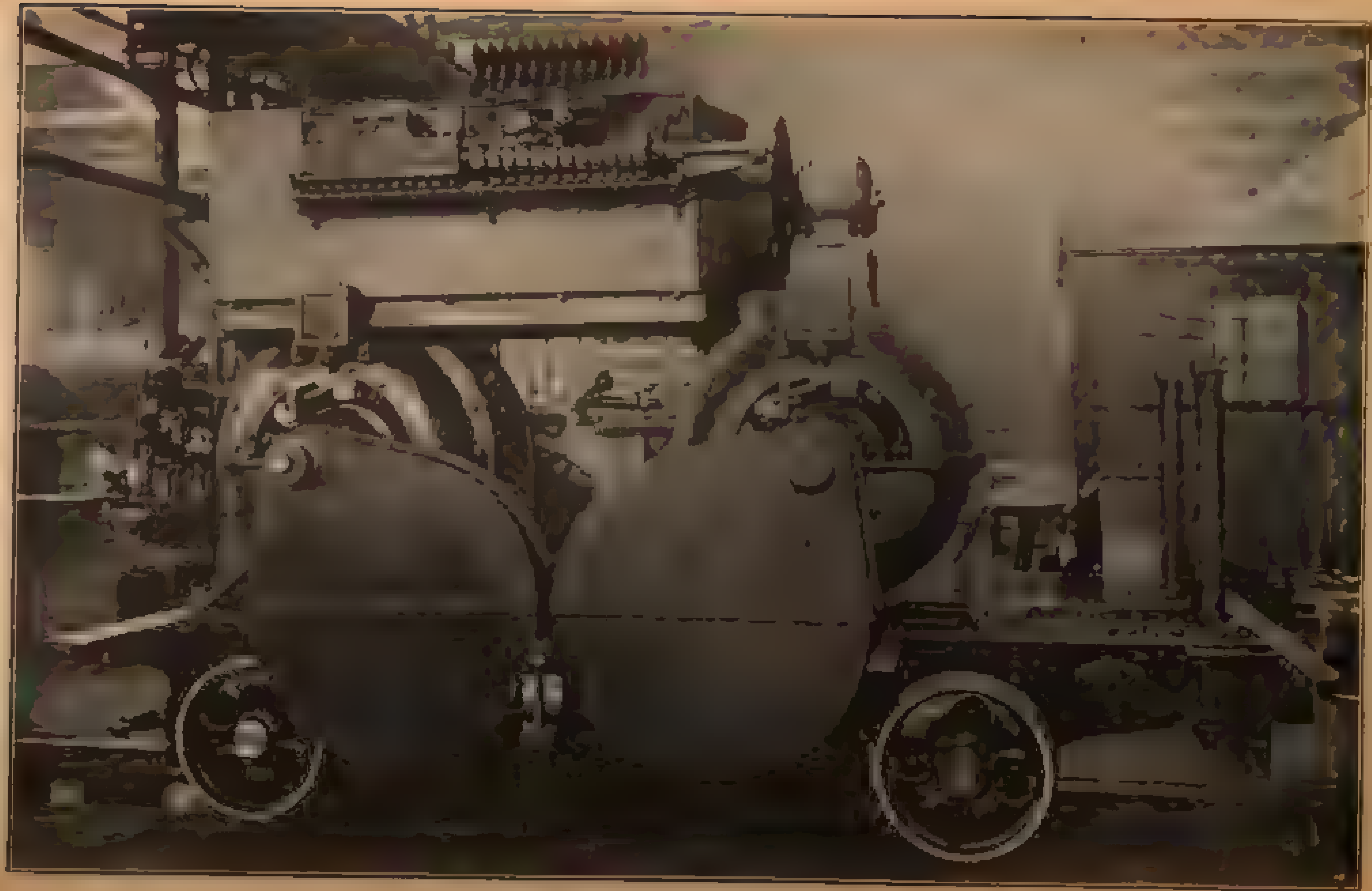


FIG. 209.—Jungfrau Railway, Locomotive No. 6.

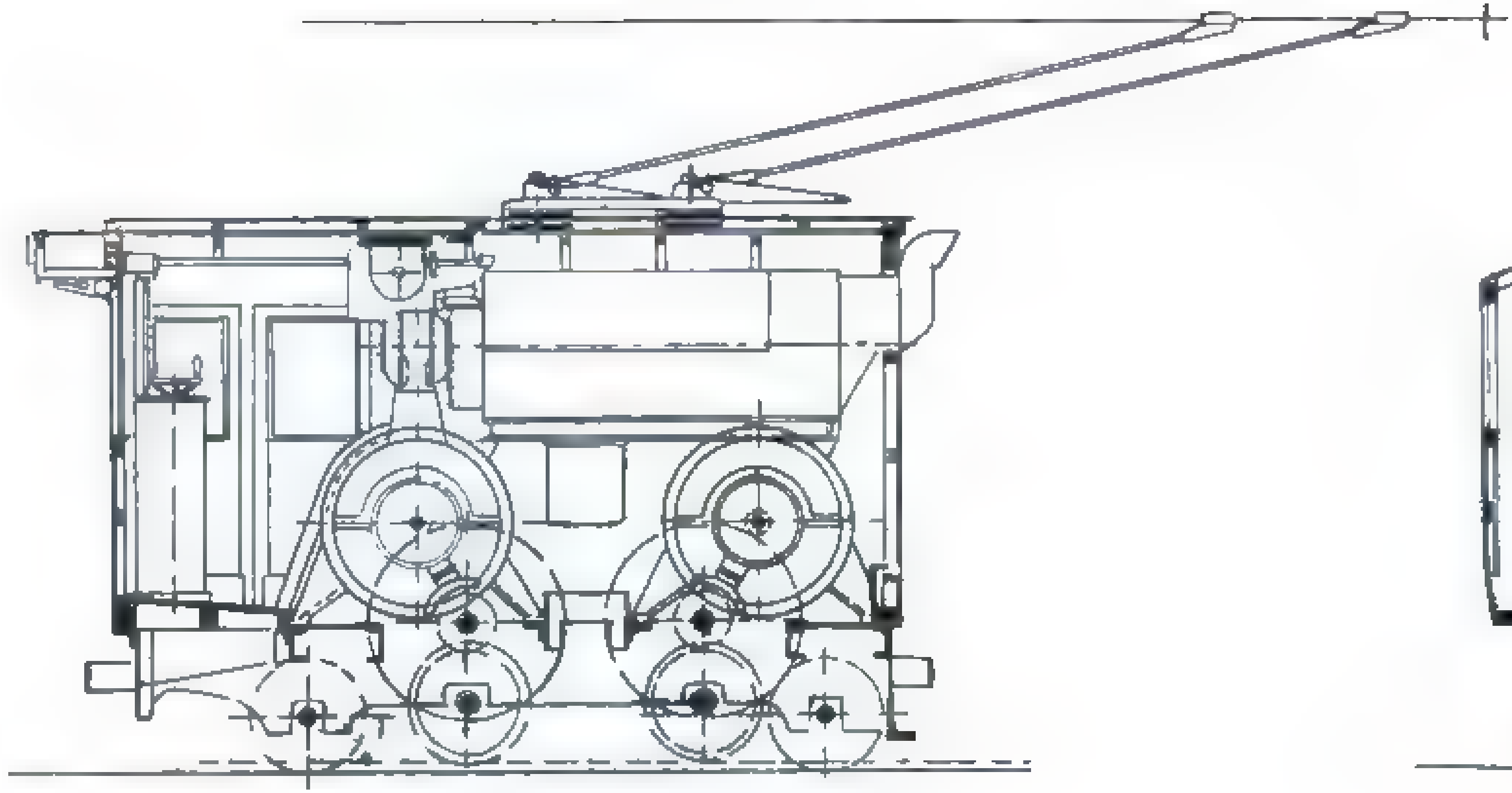


FIG. 300.—Longitudinal Section.

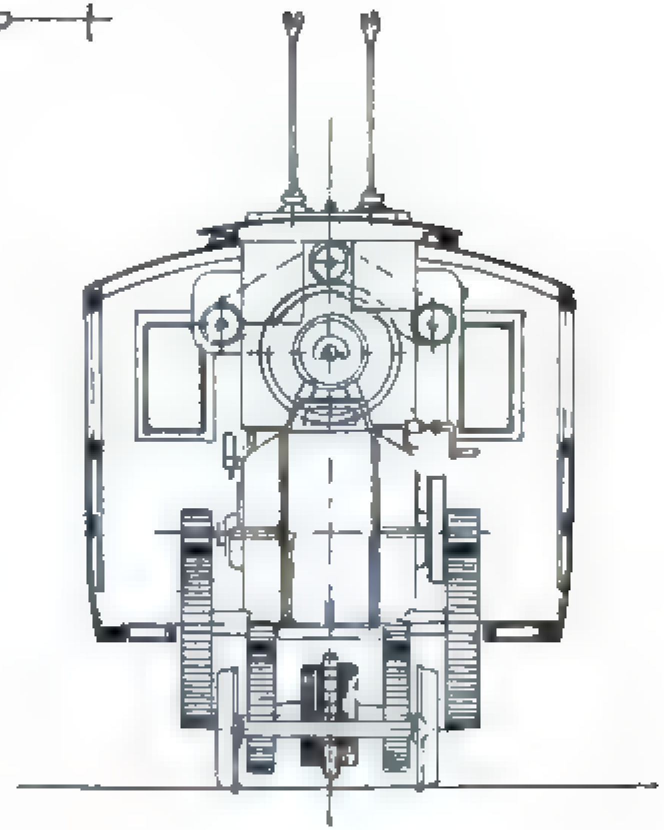


FIG. 301.—Cross Section.

Brown-Boveri 3-phase Locomotive No. 6 on Jungfrau Railway.

driving pressure upon the rack-rail, and its weight is 16·8 tons. It also carries two motors, each giving 150 horse-power when running at 760 revolutions per minute with 450–600 volts line-tension, and its normal speed is also 8·1 kilometres per hour. The speed, however, can be varied from this down to less than ½ kilometre per hour during a down run without contact with the trolley-lines. Other locomotives

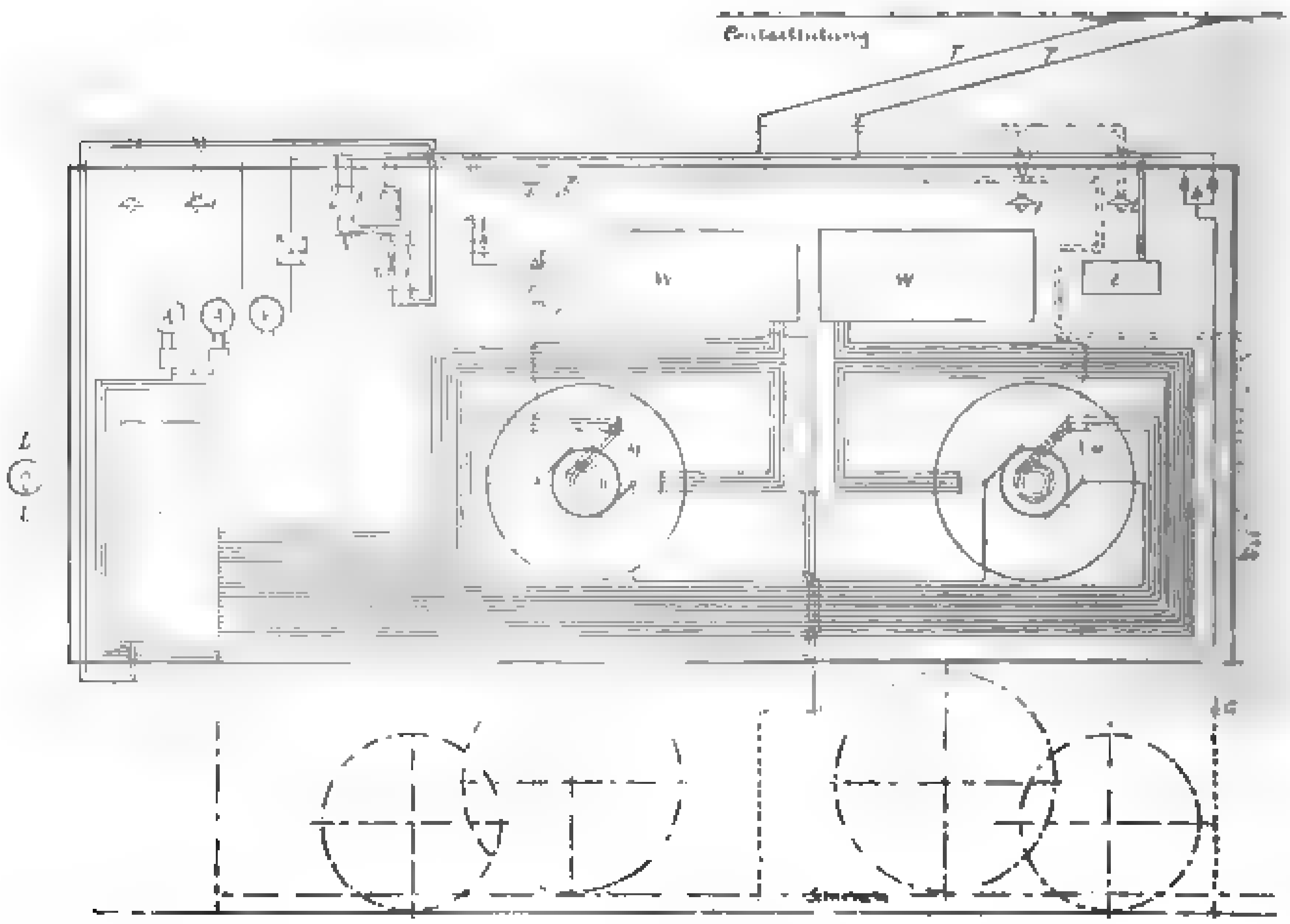


Fig. 302.—Scheme of Electric Connections on No. 6 Jungfrau Locomotive.

MM. 150-horse-power 3-phase motors and direct-current dynamos.
G. Main controller
WW. Starting and braking resistance rheostat.
N. Emergency cut-out switch.
S. Main current safety fuses.
T. Collecting-shoes.
vm. Fan-motor for cooling resistances.
a. Fan-motor switch.
s. Safety fuses to fan-motor.
t. Lighting transformer.
l. Incandescent lamps.
ab. Lighting switch.
sb. Lighting safety fuses.
L. Signal lamp.
A. Ammeter.
V. Voltmeter.
Sh. Ammeter shunts.
vw. Voltmeter resistance.
b. Lightning protector.
GGG. Earth contacts.
Sc. Coupling of lighting leads to trailer-coach.

capable of running down the line without delivering energy to the central station had already been put on the line, but with these the speed could not be lowered to less than 4 kilometres per hour without dependence upon the mechanical brakes for absorbing the gravitation energy of the descent. The general mechanical construction and gearing of this No. 6 locomotive is the same as that of the others,

except that sliding contact-shoes instead of trolley-wheels are used for the collection of the current and that there are only two, instead of four, of these. Figs. 300 and 301 show its longitudinal and cross sections, and in Fig. 302 can be traced all its electrical connections.

The motors of this new locomotive act as synchronous 3-phase induction motors on the ascent, while in descending they act as self-exciting continuous-current generators. At one end of the rotor are mounted the usual three slip-rings for connection to the regulating rheostat in the rotor circuit. At the other end is mounted a commutator, the brushes of which are lifted out of contact with it by a 3-phase magnet so long as the connection to the overhead line wires is closed, but are drawn by a spring and lever down upon the commutator segments as soon as the overhead 3-phase current is switched out. The continuous-current energy generated is led through, and

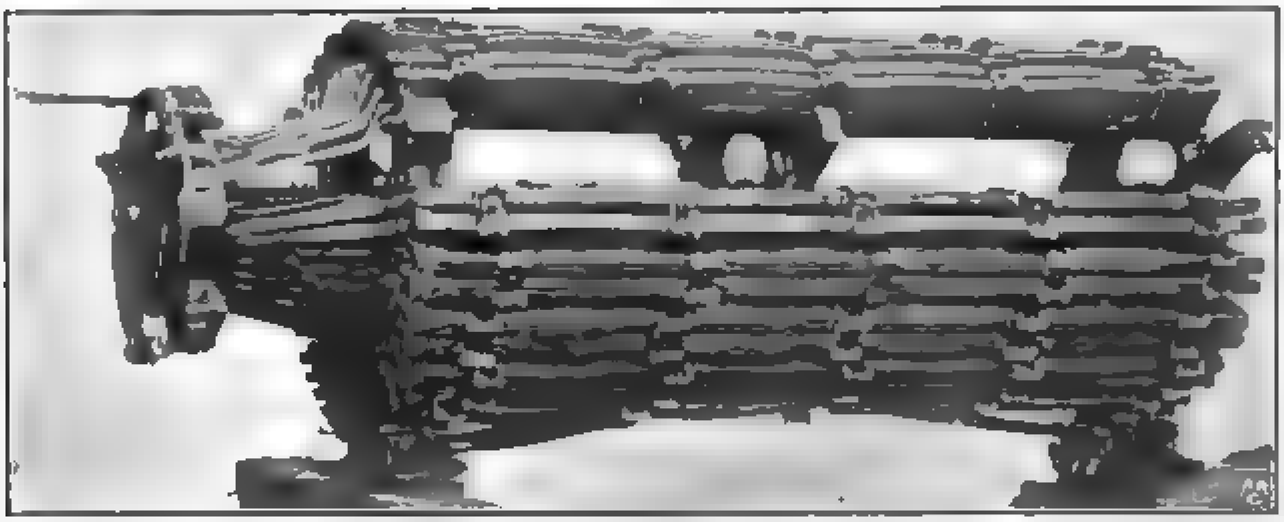


FIG. 303.—Rheostat Resistance on Jungfrau Locomotives.

absorbed by, the same resistance as is used as rheostat for the rotor circuit in 3-phase working. As seen in Figs. 298 and 299, this resistance is placed longitudinally over the motors. Its internal construction is shown by Fig. 303. It is dimensioned so as to absorb 170 kilowatts throughout a prolonged run. It is fan-cooled, the fan being motor-driven and mounted at the front end, as seen in Figs. 298 and 299. The controller parts are so interlocked that the uphill 3-phase reversing motion can only be made when this resistance is cut out, and so that the downhill direct-current reversing motion can only be made when the motors are short circuited. During direct current working, also, a too rapid cutting out of rheostat resistance and consequent change of speed is prevented by the insertion in the controller of a magnetic device rendering nugatory the throwing over of the controller handle at more than a specified time-rate. A similar device has been already described in a previous chapter.

This locomotive is furnished with all the mechanical braking apparatus described above for the others upon this line.

12. In respect of length and ordinary traffic, the heaviest 3-phase railway yet built in Switzerland is that between Thun and Burgdorf. The latter place is to some better known by its French name, Berthoud. It lies at the foot of the Emmenthal, 20 kilometres north-east of Berne on the route to Olten. This line was opened for traffic in the summer of 1899. From Thun it follows for a few miles the valley of the Aar to Heimberg, and then strikes straight north across the high country east of Berne. Its length is 40 kilometres. The power-station is 10 kilometres south of Thun, at a point where the river Kander falls into the Lake of Thun. Thus the energy is transmitted 50 kilometres = 31 miles. In the case of a central station placed in the middle of the length of railway it supplies, this is equivalent to a route-length of 100 kilometres, or 62 miles. The success of this railway is, therefore, of great interest in the problem of main-line electric traction.

The gradients are nowhere so steep as to preclude the use of ordinary adhesion-driving. The stiffest grades are 25 per 1000, or 1 in 40; but they are relatively long, four stretches at this grade, separated only by station levels, being 1545, 1112, 960, and 1980 metres long, while there are also long stretches at 21, 19, and 17 per 1000. The climb from Thun to the summit is 208½ metres in a length of 20 kilometres, giving a ruling gradient of 10·51 per 1000; while that from Burgdorf to the summit is 234 metres in 20½ kilometres distance, equivalent to a mean grade of 11·44 per 1000.

The least radius of curvature is 250 metres; and 11¾ kilometres lie in curves of from 250 to 500 metres radius, while 36 per cent. of the whole length is curved.

There are fifteen stations on the line, the mean length between them being 2·87 kilometres, while the least distance is 1¼ kilometre and the greatest 4¼ kilometres. The gauge is 4 feet 8½ inches, and Vignole rails, 12 metres long, weighing 36 kilograms per metre, are used for the track. The line is single-track throughout outside the stations. The maximum passenger-train weight is 102 tons, but the normal train weight is about 55 tons. The design is for 36 kilometres per hour maximum speed, but 40 kilometres is frequently run downhill. The normal line-tension is 750 volts, two phases of the current being collected from two overhead copper wires, while the third phase travels by the rails. The high-tension transmission is at 16,000 volts.

13. The power is taken from the river Kander by Escher-Wyss horizontal-shaft turbines, working with 63 metres fall and passing per second normally 7 cubic metres of water, with a minimum of 4 cubic metres. There are six turbines, each of 900 horse-power, and two

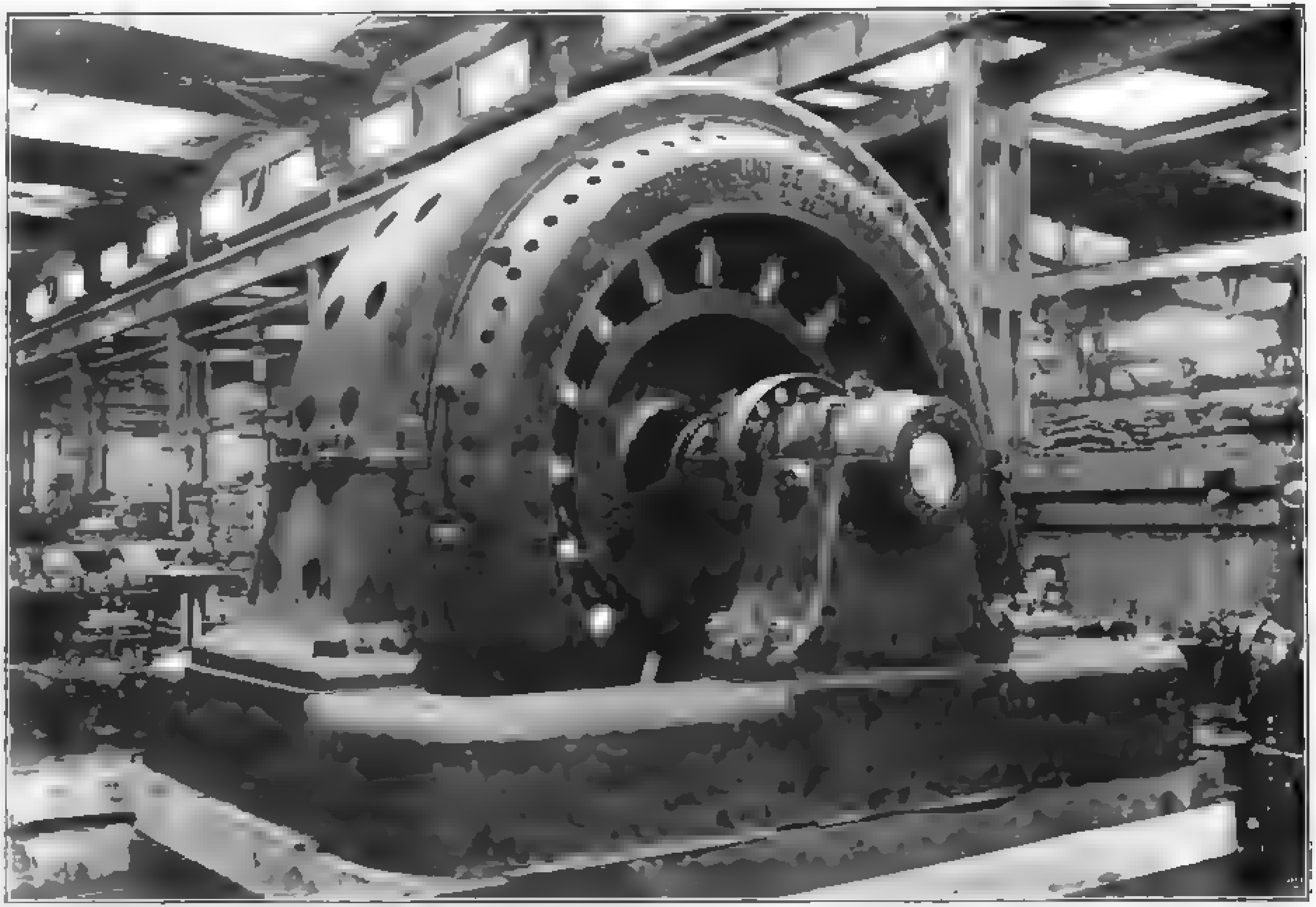


FIG. 304.—Brown-Boveri 2600 horse-power 4800 volt 3-phase Alternator for direct-coupling at 315 revolutions per minute.

small ones to drive independently the direct-current dynamos for the fields of the exciters and other station machinery. These are direct-coupled to six Brown-Boveri 3-phase alternators giving 4000 volts at 40 periods per second. These are 12-pole machines running at 400 revolutions per minute, each alternator carrying its own exciter on its shaft overhung beyond the main bearing. Fig. 304 is a view of a larger machine of the same style, yielding 2600 horse-power at 4800 volts, direct-coupled to an hydraulic turbine running at 315 revolutions per minute. The fields of the six exciters are supplied with current from two direct-current dynamos independently driven by the auxiliary turbines.

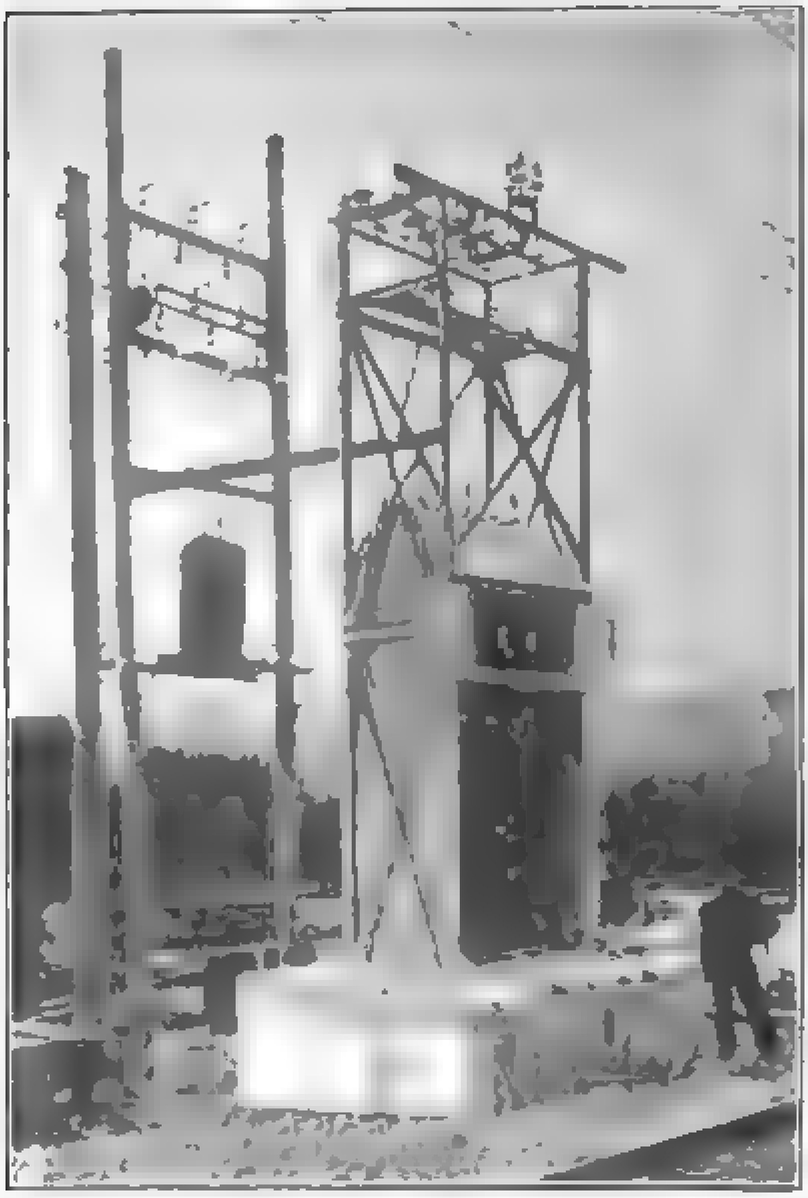


Fig. 305.—Burgdorf-Thun Railway Transformer Sub-station.

14. Some of the energy from these alternators is used in Thun and elsewhere in the near neighbourhood of the Kanderwerk at the generated 4000 volts; but step-up transformers take most of it up to 16,000 volts for transmission along the Thun-Burgdorf railway, and for the supply of power and light to the city of Berne, some 30 miles distant.

This high-tension transmission is carried as far as Thun by three overhead wires on iron lattice girder-masts spaced 50 metres apart. From a point a little beyond Thun the railway transmission is continued on timber posts, with wires of 5 millimetres diameter. The lowest wire at the centre of its dip is kept 6 metres above ground, and the average spacing of the poles is 45 metres. The insulators are double-lipped, and on every fifth pole a lighting conductor is mounted. Special lightning protection

is installed at each end of the 50 kilometres length and at each transforming sub-station. Special local difficulties led to the undesirable choice of a high-tension route separate from the track-line, which involved much extra expense in masts, lateral connections to transforming stations, and way-leaves.

15. The branches to the sub-stations are of 4 millimetres diameter wire. The longest of these lateral branches is ¾ kilometre in length. There are thirteen such sub-stations. Fig. 305 is a photograph of one of them, and Fig. 306 shows the details of its arrangement. They are of special interest because of their simple and inexpensive construction. They are all built close to the track, and the concrete foundation of the hut has a floor level only a few inches below that of the railway trucks and is laid with rails to facilitate the shipment and unshipment from the truck of the transformer when it has to be removed to the repairing workshops. The two end sub-stations are each a ½ kilometre from the track termini, and the spacing of the stations along the line varies from 2·4 to 3·4 kilometres, the mean being 3 kilometres. Each station contains one 3-phase oil-cooled transformer of 450 kilowatts maximum capacity, sufficient for one 102-ton train on its section. It is wound to reduce the voltage from 16,000 to 750; but by tapping the primary at suitable points this ratio of reduction is reduced on the more distant parts of the route so as to compensate for the drop of high-tension voltage from the initial 16,000. The hut is of corrugated sheet-steel, and the leads are brought in through the roof incased in porcelain tubes. Horn lightning protectors of the high-tension line, with 18 millimetres spark-length and resistances inserted on the path to earth, are mounted on the framework carried by the roof of the hut. The 3-pole switch for disconnecting the sub-station from the high-tension line is in the open upon a separate timber framed-standard erected 3 metres behind the hut. This switch stands 6 metres above ground, and is worked from ground-level by a lever linkage. Three-pole section-switches are placed on the secondary at each sub-station, and similar lightning protectors earthed to the rails are mounted on these secondaries.

16. The two overhead contact-wires are of 8 millimetres hard-drawn copper, suspended, with duplex insulation, by 6-millimetre steel span-wires. In and close to the large end stations and upon the longer bridges these are carried by iron side-posts, and on timber masts elsewhere, except in tunnels where the span-wires are attached to eye-bolt insulators cemented into the masonry. The average spacing of the suspensions is 35 metres. As bows are used as collectors, the two contact-wires are, in plan, arranged with a small zigzag, so as to distribute the wear along the contact-length of the bow, and no special side-strain attachments are required at curves. At crossings

and turn-outs one of the two wires is suppressed on each track, or rather an insulated dead length of wire is substituted for it. As there are two collectors mounted fore and aft on each motor-coach and each locomotive, with a distance apart greater than the length of this insulated dead wire, no interruption of the full 3-phase supply is caused at such crossings.

17. There is one special point about the design of the rail third-phase return that is well worth noting. The bonding of rail-returns is the feature that has always given most trouble on tramways. Mm. Brown-Boveri have patented a method of doing without copper bonds, and have applied it to the railway now described. The only bonds are the fish-plates. The inside surfaces of these, as also the

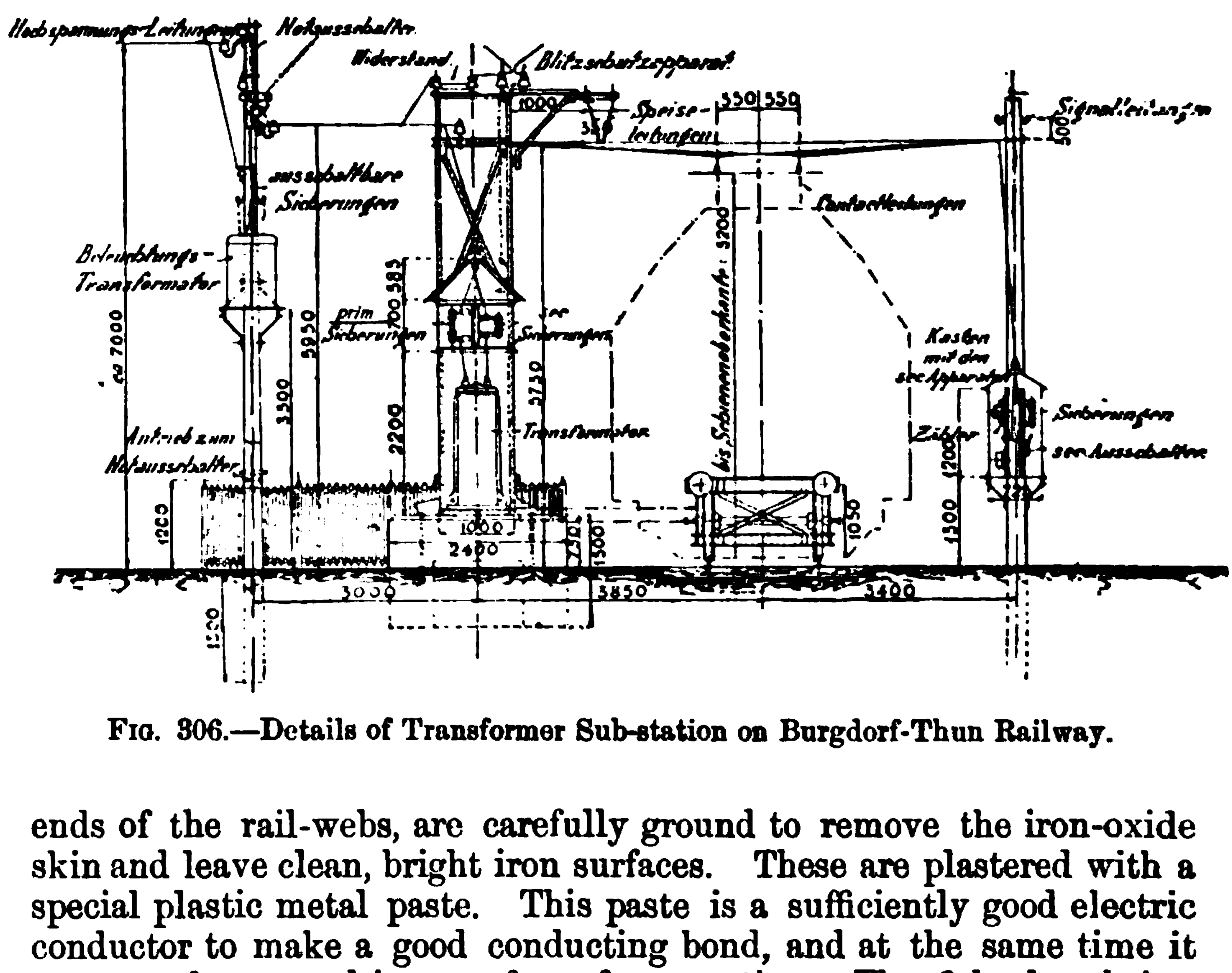


FIG. 306.—Details of Transformer Sub-station on Burgdorf-Thun Railway.

ends of the rail-webs, are carefully ground to remove the iron-oxide skin and leave clean, bright iron surfaces. These are plastered with a special plastic metal paste. This paste is a sufficiently good electric conductor to make a good conducting bond, and at the same time it protects the ground iron surfaces from rusting. The fish-plate being bolted up hard on the rail-flanges in the ordinary manner, only a very thin layer of paste is left in the inside of the joint. Eight-millimetre copper wire is used for cross-bonding the two rails at 96-metre spacings. Eighteen per cent. drop of voltage is allowed along the contact-line when the heaviest train is upon it, this high percentage being rational on account of the infrequency of the train-service.

18. Figs. 307 and 308 give elevation and cross-section of one of

the motor-coaches, which weighs 32 tons empty and contains 66 seats, giving a weight of 485 kilograms per seat.

It will be noted that on its roof are mounted two pairs of bow-collectors, fore and aft. These can be thrown over for running in

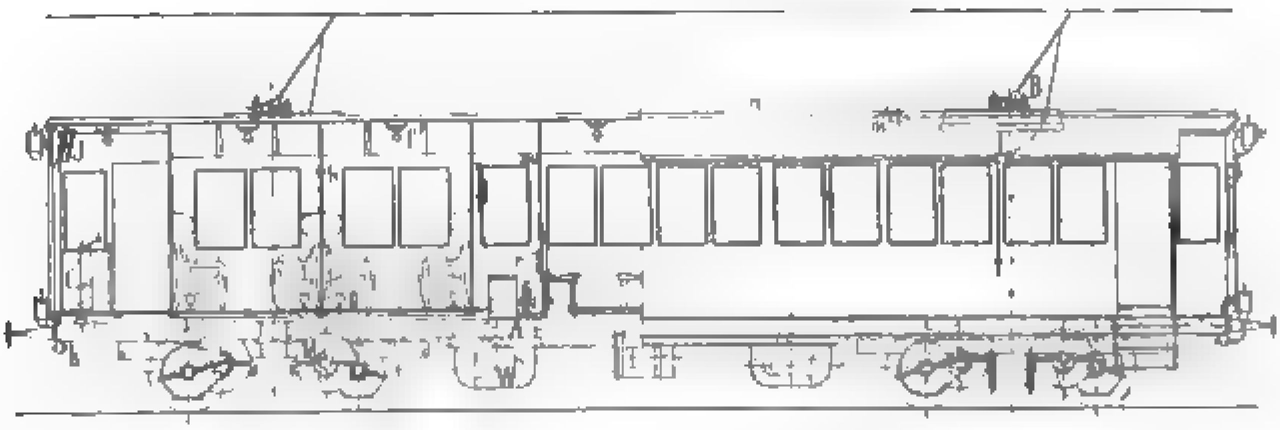


FIG. 307.—Burgdorf-Thun Motor-coach—Elevation.

either direction. In each pair the two bows which collect from the two wires, have completely independent movements and spring supports. The collecting cross-bar of each bow is of triangular tube, so that there is a flat rubbing surface of considerable breadth. Four thousand kilometres run is stated to be the life of one of these tubes. The tube can be turned on end bearings, so that it has three wearing surfaces to be used alternately or successively. The rest of the bow is made from thin round steel tube braced diagonally by stout steel wire.

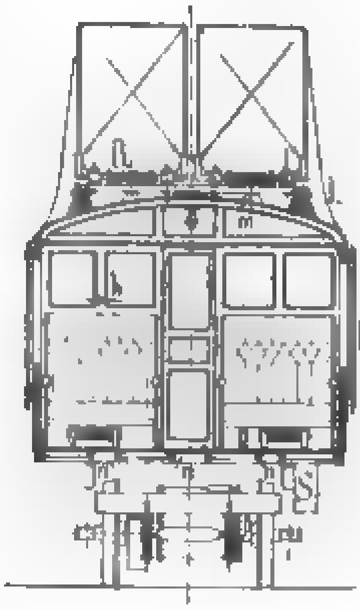


FIG. 308.—Burgdorf-Thun Motor-coach—Cross Section.

The coach is mounted on two bogie-trucks, with four 60-horse-power 3-phase motors, one geared to and driving each axle, with normal tramway spring nose-suspension. The gear ratio is 1 to 3, and at synchronous speed the motor revolutions are 600 per minute, corresponding to 36 kilometres travel per hour. One motor weighs 1½ ton, and the total electrical equipment accounts for 10 tons out of the 32 tons gross weight of the coach. The coach has a total length of 16·3 metres over buffers, a wheel-base of 9½ metres between bogie-pins of the two trucks, and a wheel-base 2·2 metres in each truck. Two resistance boxes, marked W in Fig. 307, are carried under the frame. An 18-kilowatt step-down transformer reduces the 750 to 100 volts for lighting, for the 4-horse-power air-pump

motor for the Westinghouse brakes, and for the control currents. Each coach has mounted on its roof a lightning protector with choking coil and spark-resistance on the path to earth. The motors are all alike and all used in parallel, and the control consists simply in gradual cutting out of the starting resistance inserted in the rotor circuit of each. As this is cut out, the speed approaches synchronous speed, the horse-power gradually increasing to a maximum at a little below synchronous speed, and then decreasing rapidly to zero at full synchronous speed. On down gradients the trains are run above synchronous speed, and the motors become generators of 3-phase energy, which they deliver by the bow-collectors to the overhead line and thus lighten the load on the nearest transformers due to simul-

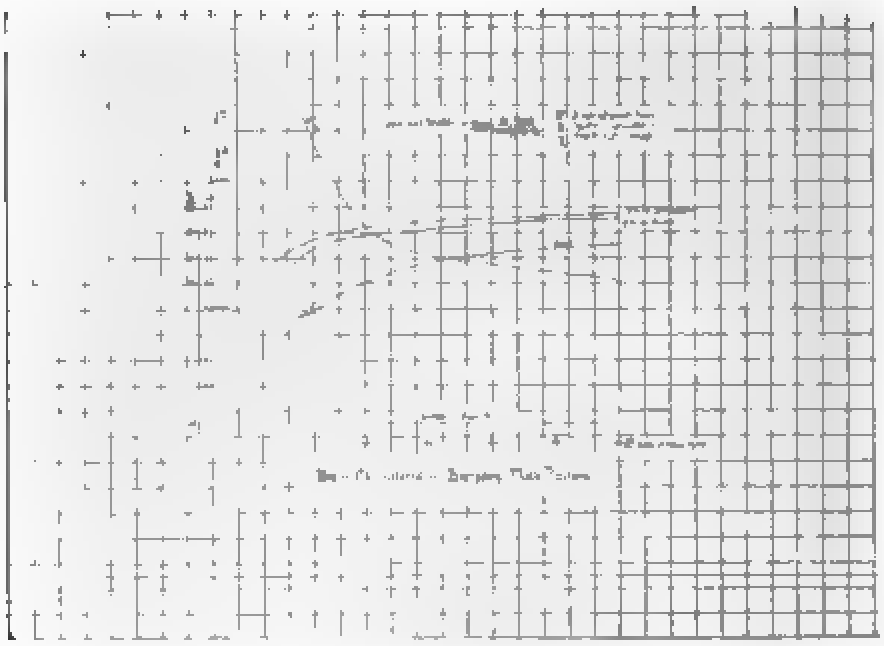


FIG. 309.—Burgdorf-Thun Motor-coach—Motor Characteristics.

taneous up-grade trains. This recuperation does not come much into play, however, on the Burgdorf-Thun railway except near the central summit of the route, firstly because the main long + and − gradients are far apart, and secondly because the train time-service in the present development of the service is not frequent enough to develop the full advantages of 3-phase recuperation or balancing.

The combined efficiency of these motors and their gearing in the motor-coaches is 85 per cent. at full load, 78 per cent. at two-thirds load, and 71 per cent. at one-third load.

Fig. 309 gives the characteristic curves of these geared 3-phase motors on the motor-coaches. The two curves marked η give the efficiency exclusive of frictional loss in the gearing. From full down to one-third load there is very moderate reduction of efficiency.

Running as motor, it sinks from 85½ per cent. at 60 effective horse-power, measured at the wheel-tyres, down to 79 per cent. at 20 effective horse-power. When used as generator, the efficiency is greater, being 87½ and 82 per cent. at full and one-third load.

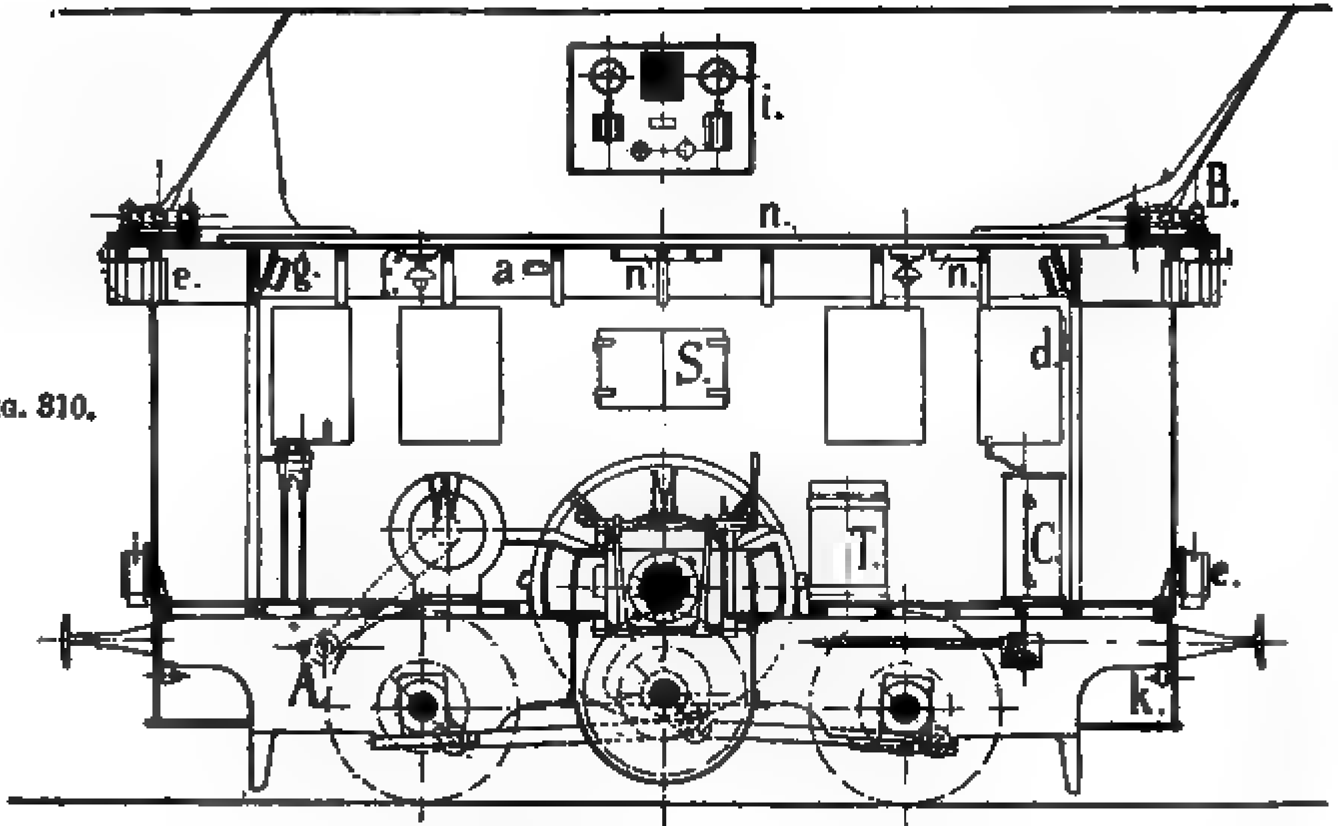
The power-factor, $\cos\phi$, which is the cosine of the angle of phase-difference between the currents in the stator and in the rotor, varies similarly to the efficiency, but in more rapid ratio. It is 0·76 at full load and 0·60 at one-third load.

The real kilowatt equals the apparent kilowatt multiplied by $\cos\phi$ and by the efficiency. The curve marked $\frac{SW}{HP}$ gives the ratio of apparent watts to actual effective horse-power at the rails, taking account of the frictional inefficiency of the gearing, the apparent watts and the brake horse-power at the wheel-tyres being obtained directly from test measurements. This ratio of apparent watts to actual developed horse-power sinks rapidly at first from 10 to 25 horse-power—mainly on account of the increase of $\cos\phi$, but also because of the increase of the efficiencies—and then at a slower and nearly uniform rate up to full load. It is 2500 at 10 horse-power; 1650 at 20 horse-power; 1420 at 30 horse-power; and 1220 at 60 horse-power. Since 736 watts equals 1 horse-power, this ratio would be 736 if the phase difference were zero and if the electric and mechanical efficiencies were each unity. The ratio equals $\frac{736}{\eta\eta_1 \cos\phi}$ where η and η_1 are the electrical and the mechanical efficiencies, the former covering the iron magnetic hysteresis as well as the copper ohmic losses.

19. Figs. 310, 311, and 312 give elevation, cross-section, and plan of the 3-phase locomotive used here, and Fig. 313 gives a photographic view of this curious machine. Fig. 314 shows very clearly its general arrangement with the cab and small accessories removed.

It is furnished with two pairs of bow-collectors as is the motor-coach. It has two running axles only, with a wheel-base of 3·14 metres between them. Its total length over buffers is 7·8 metres. It is driven by two motors, each of 150 rated horse-power, which are keyed on the two ends of one shaft lying in the middle of the length of the locomotive and above the floor of its frame. As seen in the drawings, where the motors are marked MM, these overhang the main-bearings of this driving-shaft, outside the frame and outside the running-wheels. The bearings are made very long, and are built very stiffly into the frame. These and the other bearings in both the locomotive and the motor-coach have ring-lubrication, which is said to answer extremely well—owing, presumably, to the very moderate travelling speed of 21½ miles per hour. Immediately underneath this shaft, and, therefore, also in central position, is placed a second gear-shaft with bearings in the lower parts of the side-plates of the frame, which

Fig. 310.



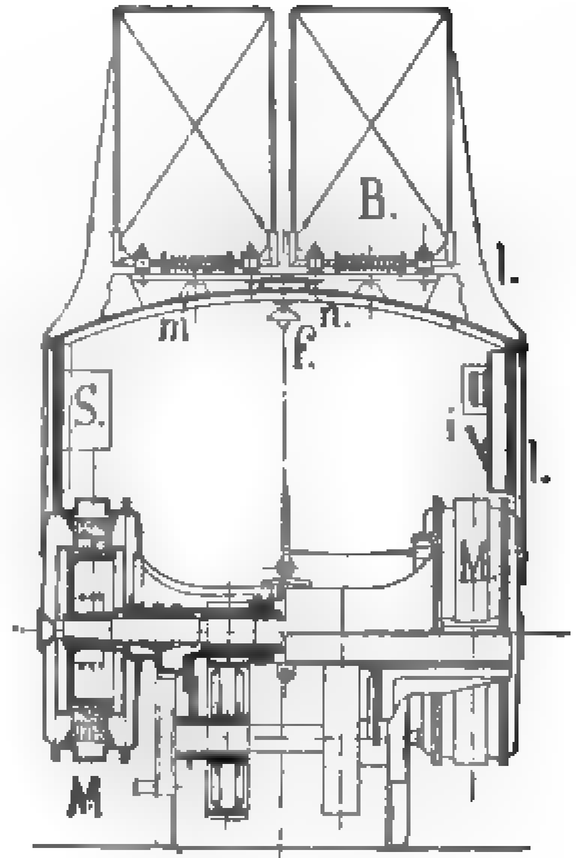
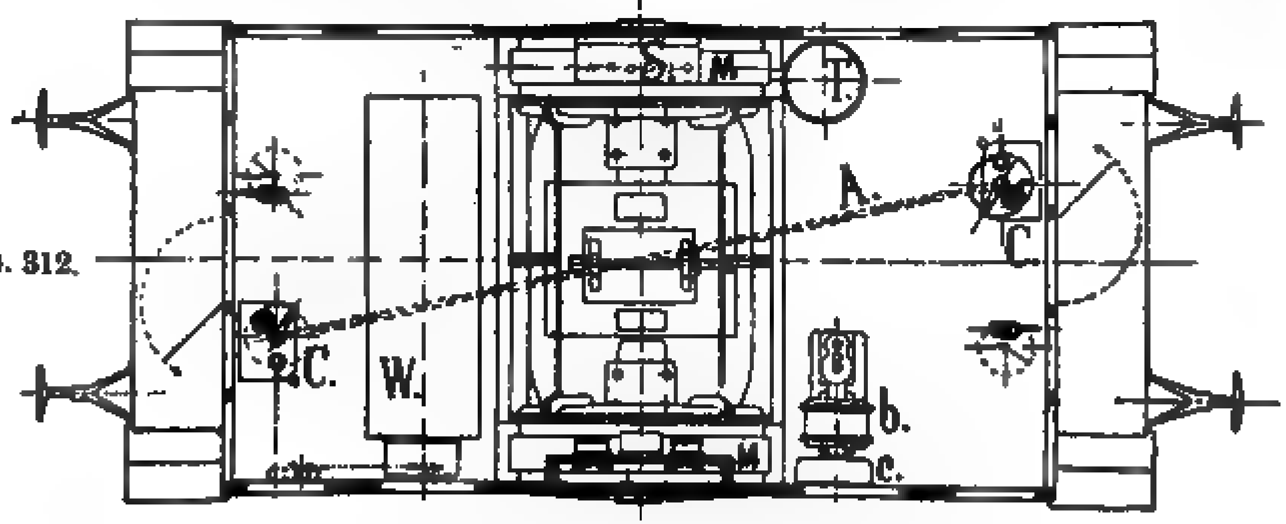


Fig. 311.

Fig. 312.



Burgdorf-Thun 3-phase Locomotive.

Fig. 310.—Elevation.
Fig. 311.—Cross Section.
Fig. 312.—Plan.

side-frames lie inside the running-wheels. The motor-shaft is geared to this by a pair of helical spur pinions and wheels, one gear on each side of the longitudinal centre-line. A toothed clutch on the middle of the motor-shaft, sliding on a feather on this shaft, couples one or other of the two pinions to the shaft, the pinions otherwise running loose on it. The two gears are in the ratios 1 to 1·86 and 1 to 3·72, and correspond to travelling speeds 36 and 18 kilometres per hour with the motors running near synchronous speed. This synchronous speed is 300 revolutions per minute. The higher gear

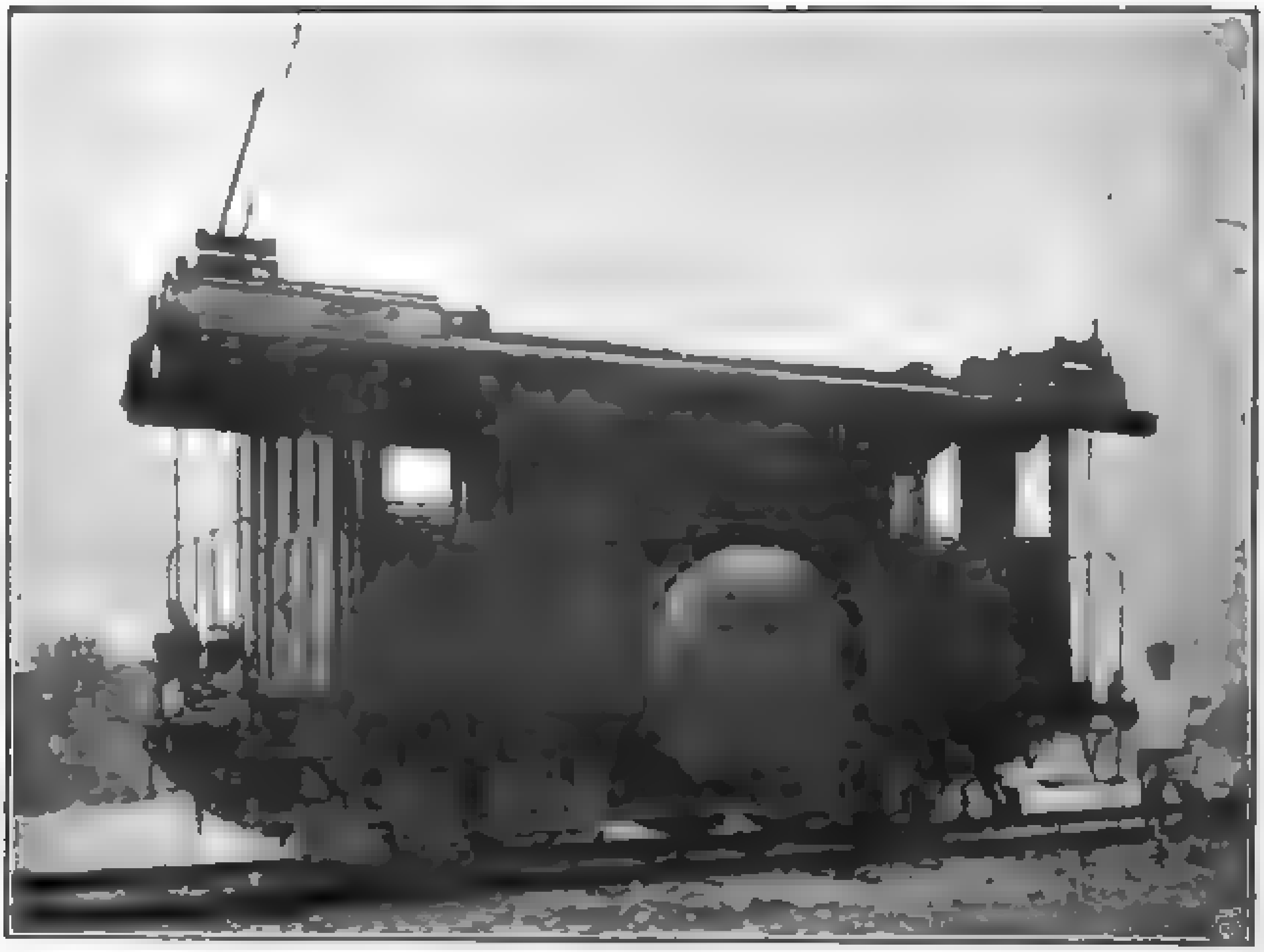


FIG. 318.—Burgdorf-Thun 3-phase Locomotive—Photographic View.

is used for heavy goods and "double" passenger trains on the steepest inclines.

This second axle has a balanced outside crank on each end of it, and each crank-pin is coupled by two fore-and-aft coupling-rods to similar outside cranks on the running-wheels. This coupling-rod transmission permits of both driving-gear shafts having bearings fixed rigidly in the frame which carries, also rigidly mounted on it, the stators of the two motors; while at the same time the axle-boxes of the running-axles may carry the underframe with any pattern of spring-suspension desired.

At any one instant freedom of up-and-down motion of the axle-boxes in the horn-plates would be given without any accompanying rotation of the axles and wheels if the horn-plates were curved to a centre coinciding with the simultaneous position of the crank-pin of the middle driving-shaft. During the rotation, however, this crank-pin occupies successively positions all round the crank-pin circular path, so that it is impossible to satisfy fully the above condition of giving complete freedom of swing to the axle-boxes. The mean position of the crank-pin, that is, the centre of its shaft, is therefore chosen as the centre to which are curved the fore-and-aft pairs of horn-plates, as seen in Fig. 310. In a degree corresponding inversely to this geometrical approximation to the true shifting position of the centre of curvature, an up or down swing of the axle-box (it is really the

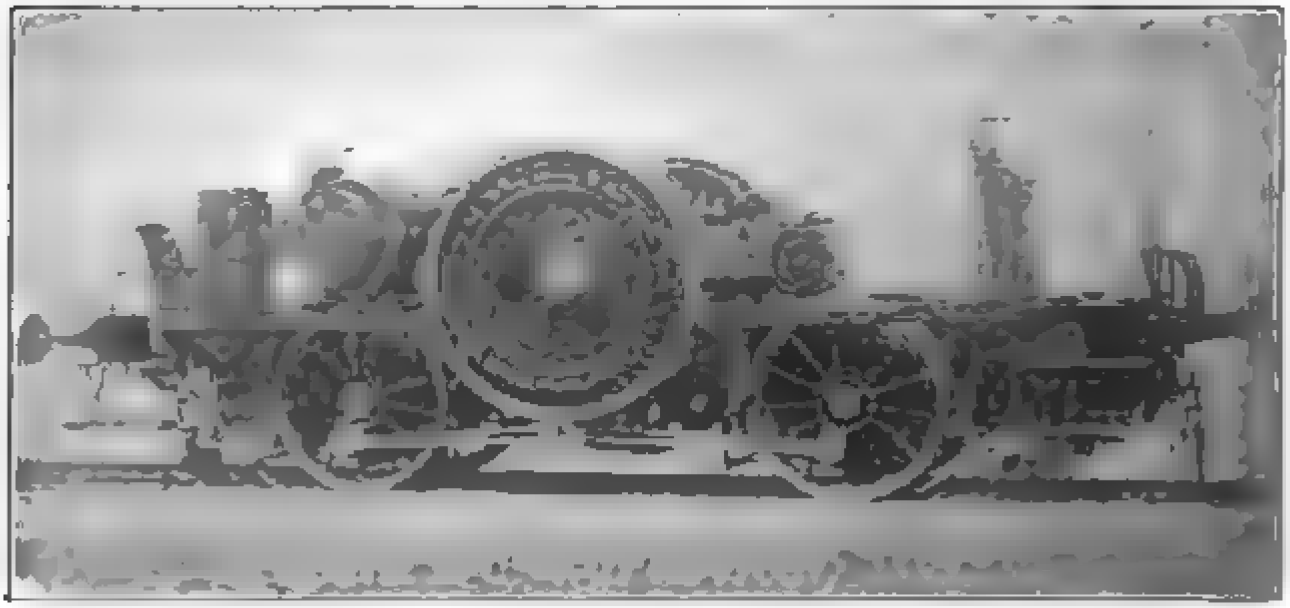


FIG. 314.—Burgdorf-Thun 3-phase Locomotive with Cab removed.

frame that swings, not the axle-box) compels a small rotation either of the running-axle or of the driving-shaft, this meaning a forward or backward rotative acceleration. As the adhesion of the wheel-tyres on the rails prevents this acceleration occurring in the running-axles, it takes place in the driving-gear, and must produce extra strain and stress upon the shafts and teeth. In order to avoid dead-points in this coupling-rod driving, the two cranks at the two ends of each shaft are placed at right angles.

Each of these locomotives weighs nearly 30 tons; each motor weighs 4 tons, and the whole electrical equipment, inclusive of 8 tons motors, about 10 tons. A single starting resistance (W in Fig. 310) serves for both motors. The cab has a driving-platform at each end, the controller and all the driving-handles being duplicated. The

efficiency of the motors and driving-gear combined is 82 per cent. at full load, 76 per cent. at two-thirds load, and 68 per cent. at one-third load.

20. Fig. 315 is an extremely interesting diagram giving the results of test measurements made when a 55-ton train of one motor-coach and two trailer-coaches was passing southwards over the up and down 25 per 1000 grades on either side of the summit. The

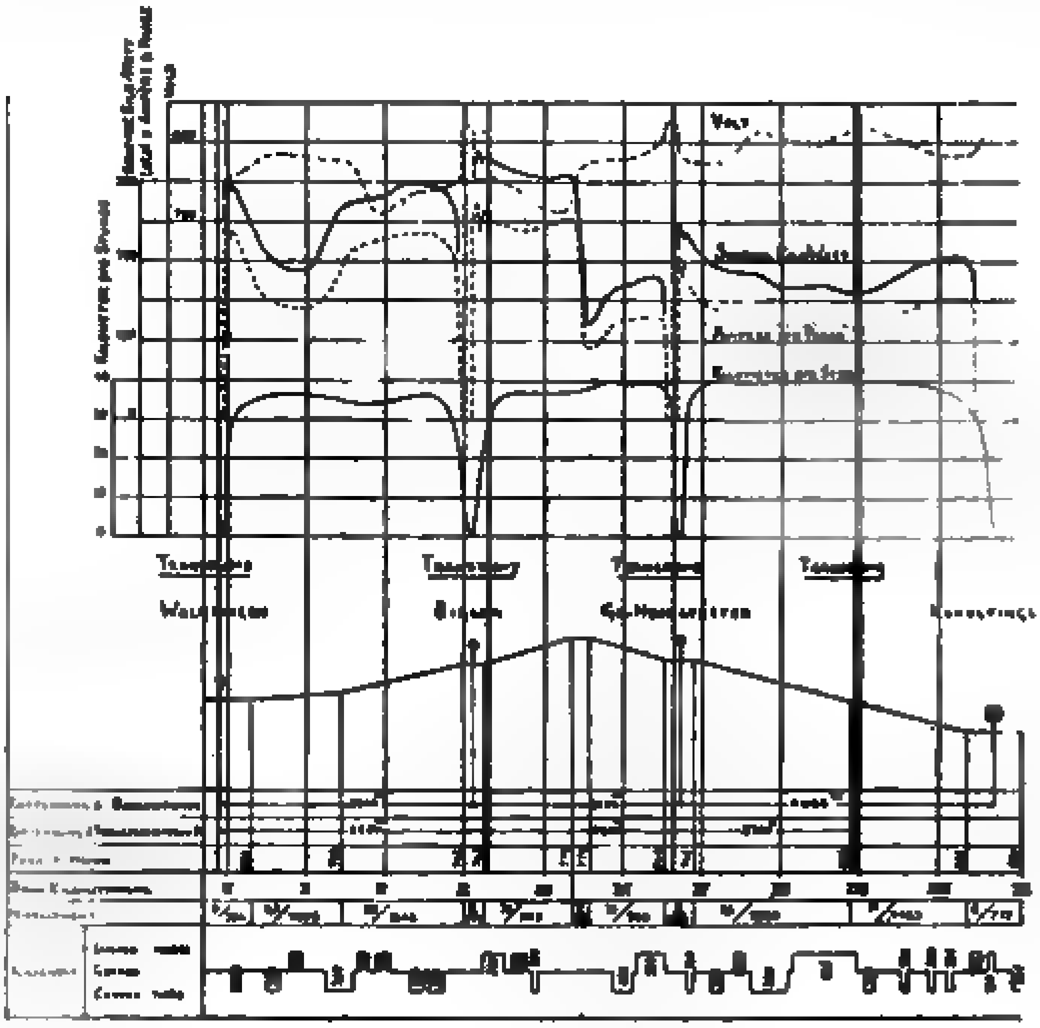


Fig. 315.—Diagram of Speed, Current, Voltage, and Apparent Kilowatts on Up and Down 25 per 1000 Grades.

lower part of the diagram gives the curves, gradients, distances, and profile of this part of the line. The train was fed from Nos. 6, 7, 8, and 9 transformers, whose positions are marked. The lowest curve gives the speed, with the four stops at the four stations. On the down incline south of the summit the speed remains steady at 40 kilometres per hour, outside the limits of initial acceleration and the braking; while on the up-grade north of the top it is 37–38 kilometres per hour. The controller and the resistances were in exactly the same positions in the two cases, and the above small difference of speed well illustrates how these 3-phase motors automatically

accommodate themselves to very large differences of load. The difference of actual load is only partly shown by the dotted current curve marked "ampère pro phase," because the readings were taken at the transformer station and not on the train. The full-line curve marked "scheinb. kilowatt," or "apparent kilowatt," also fails to measure the full difference of load, both because of the above reason and because the power-factor, or cos ϕ, varies largely from up to down grade. It will be noted that the top dotted curve of voltage is higher on the down-grade than in ascending, the loss of voltage in the line during ascent being heavier in proportion to the larger current taken. The two average voltages are 750 and 800, measured in the sub-station. Measured on the train, the difference would, of course, be considerably greater.

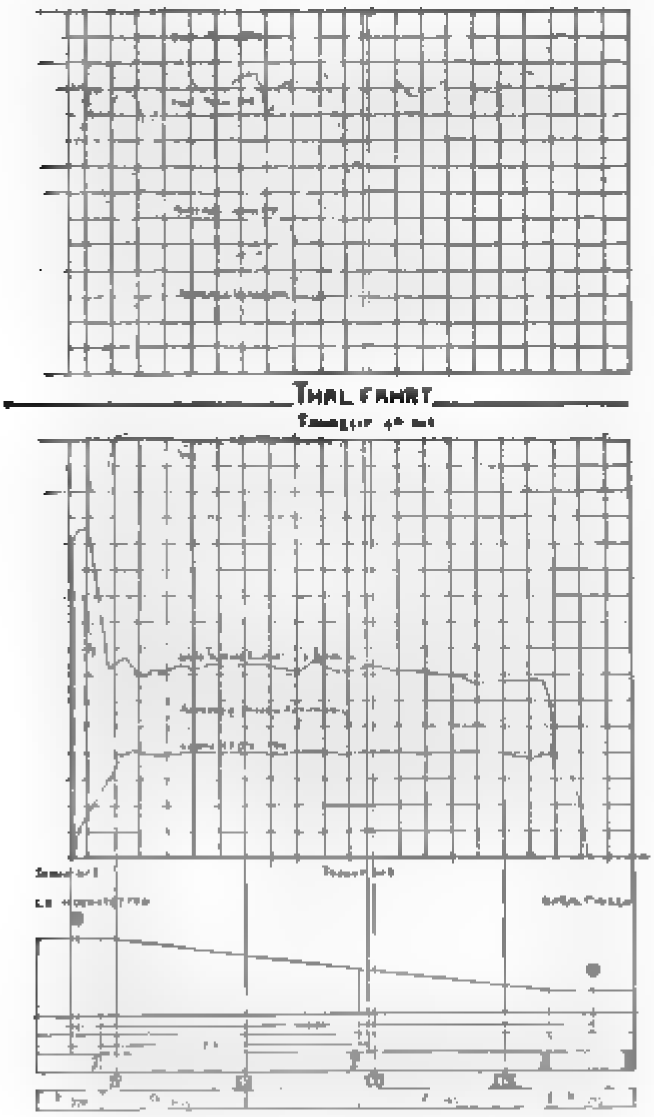


FIG. 316.—Diagram of Speed, Current, Voltage, and Apparent Kilowatts on Train and in Sub-station running Southwards on 25 per 1000 Down-grade.

Figs. 316 and 317 are still more interesting. They are for a 102-ton train of two motor-coaches and three trailer-coaches on the 25 per 1000 incline just south of the summit. Fig. 316 is for the southward or down run; while Fig. 317 is for the northward up run over the same ground. The upper part of each diagram gives in each case the volt and ampère readings in the two transformer stations from which the train is being fed. The crossing of the two current curves at the two stations must be noted. The voltage curves also cross correspondingly.

The lower sets of curves are from readings on the motor-coach itself. During the down run (Fig. 316) all the curves remain remarkably steady outside the initial acceleration and braking periods. In the up run (Fig. 317), from station No. 9 to station No. 8, the ampère-curve rises rapidly, while the voltage curve falls as quickly, the apparent watts changing very little.

Comparing Figs. 316 and 317, it is to be noted that the difference in voltage between the up and down runs is very much more upon the train than in the sub-stations.

21. Each transformer station is, on the average, loaded for only 10 minutes as a train passes it; and as this occurs 24 times

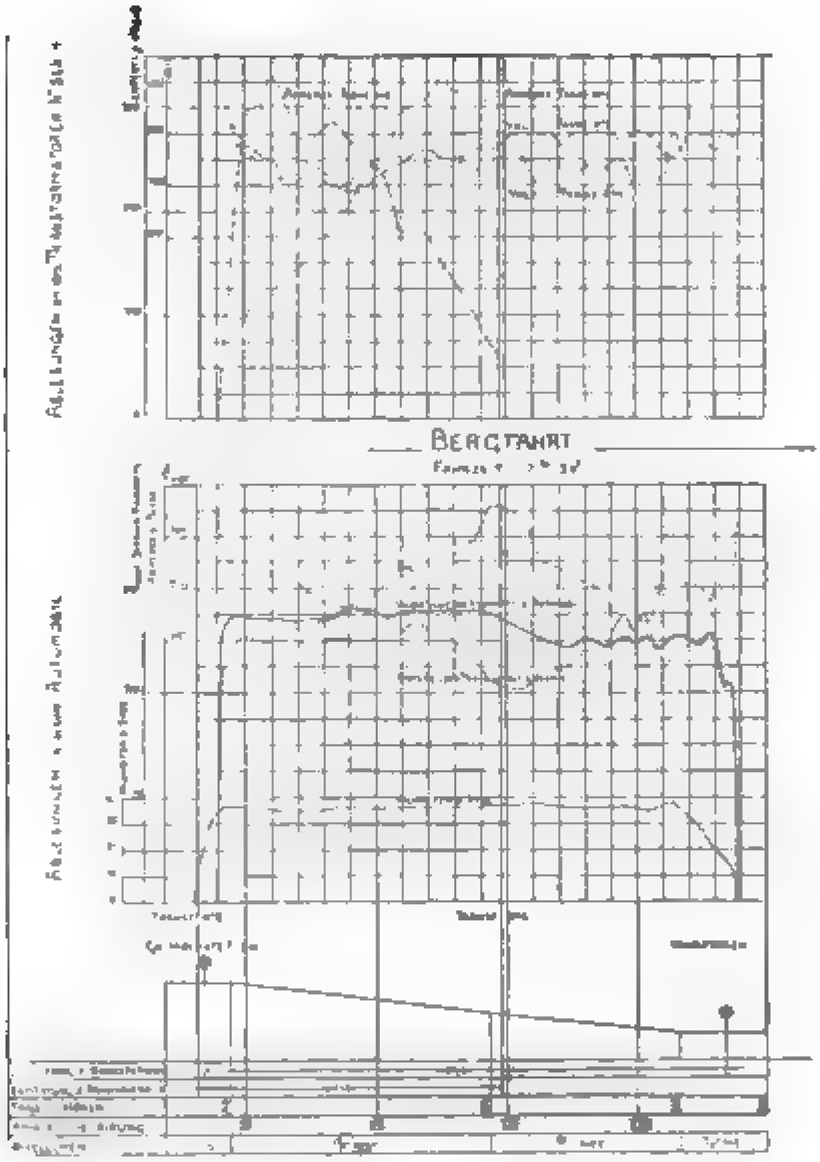


FIG. 317.—Diagram of Speed, Current, Voltage, and Apparent Kilowatts on Train and in Sub-station running Northwards on 25 per 1000 Up-grade.

per day only, the load-factor is small. The capital costs, therefore, bear an unduly large proportion to the power costs, and with a fuller train-service such as will be developed, it is hoped, in the future, the total working will become materially more economical.

The capital outlay on the construction was given in 1900 as follows:—

	Francs.
High-tension line with branches to transformer sub-stations	140,000
Fourteen transformer stations, each of 450-kilowatt capacity	160,000
Contact overhead duplex line and return-rail bonding	350,000
Station lighting and repair workshop	20,000
Six motor-coaches and two locomotives	235,000
Reserve fund	30,000
Francs	935,000

22. There may also be mentioned two other 3-phase railways in Switzerland of less magnitude than the above.

One of these, from Stansstad to Engelberg, is partly an adhesion and partly a rack line. It was opened in the autumn of 1898. It is

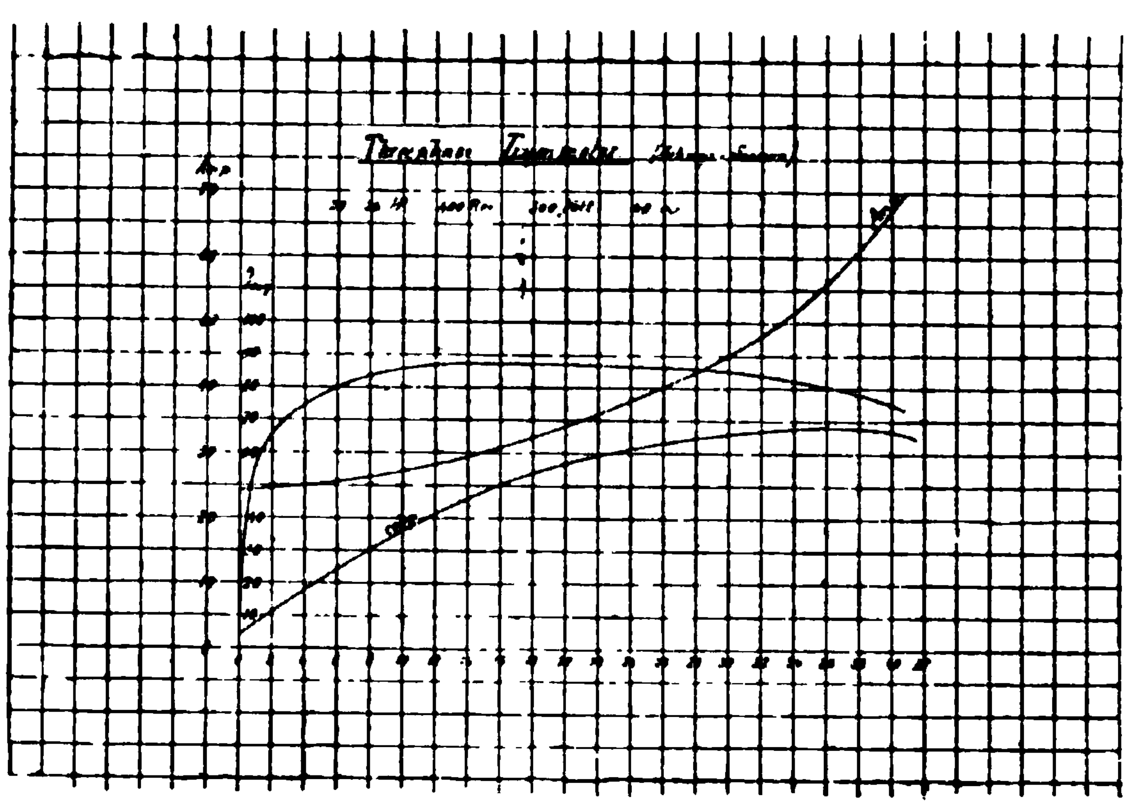


FIG. 318.—Schwyz-Seewen 3-phase Tram-motor—Characteristics.

single-track and is 22½ kilometres in length. The gradients on the adhesion portion rise to 5 per 1000, and on the rack portion to 250 per 1000, or 1 in 4. Water power is obtained by three turbines yielding in all 540 horse-power. The generators give 750 volts at 32 periods per second; and the same voltage is used along the line, on which there are two overhead wires from which the current is collected by bows. Both locomotives and motor-coaches are used, the locomotives on the rack line having each two 75-horse-power motors, and the motor-coaches two motors of 35 horse-power each.

The other line, between Schwyz and Seewen, near Brunnen on the Lake of Lucerne, runs along the high-road, and is therefore really a tramway. It is 2 kilometres long, single-track, and was opened in the autumn of 1900. Its steepest gradient is 60 per 1000. Three water turbines of total 1650 horse-power supply it with 500-volt 3-phase current at 40 frequency. Two overhead wires and trolley-collectors are used, and the motor-cars are driven each by two 20–25-horse-power motors. Fig. 318 is a diagram giving the leading characteristics of these 500-volt 3-phase motors. The curves give the current, cos ϕ, and the efficiency η to a horse-power base. Cos ϕ runs

FIG. 319.—Direct-current Haulage Locomotive on Simplon Tunnel Construction.

from 0·41 at 12 horse-power to 0·68 at 36 horse-power; while η ranges from 0·88 to 0·80 between the same limits.

23. It should be mentioned that Messrs. Brown, Boveri and Co. have also equipped many direct-current railways and tramways. Among the more important and interesting of these may be cited that up Mount Vesuvius, that between Lyons and St. Just—both of which include portions of steep rack line—and that between Paris and Versailles.

In view of the completion of the Simplon Tunnel just previous to the publication of this book, it may be interesting to give (see Fig. 319) an illustration of one of the direct-current Brown-Boveri

FIG. 320.—Direct-current Dynamo for direct-coupling to Turbine—1000 horse-power; 120 volts; 180 revolutions per minute.

locomotives that have done the bulk of the haulage during the progress of this great engineering work.

Fig. 320 is an interesting example by the same makers of a direct-current traction dynamo arranged on a vertical shaft for direct-coupling to a horizontal turbine. This is the arrangement of turbine and dynamo adopted on the American side of Niagara Falls—where, however, alternating current is generated—and it is one that has many substantial advantages, although it requires a powerful overhead crane to lift the field or armature out of place for examination and repair. The construction of Fig. 320 permits of the removal of either field or armature separately, the one being removed without disturbing the other. It is a 120-volt machine developing 1000 horse-power at 180 revolutions per minute.

24. The 3-phase generators mentioned above are for direct-coupling to turbines, and are therefore high-speed and of relatively small diameter. Fig. 321 illustrates a 1275-horse-power 3-phase alternator running at 75 revolutions per minute direct-coupled to a horizontal reciprocating engine. Here the armature is stationary and external. The large diameter gives the internal rotating field very ample fly-wheel capacity. The alternator drives its own exciter by a belt. This type of alternator is built up to double the horse-power illustrated in Fig. 321 and up to the highest voltages.

Fig. 322 shows a Swiss alternator of this same type, but of different pattern. It is of 2200 horse-power, running at 93½ revolutions per minute, and giving 3700 volts. Here the external armature is wholly carried by, and fixed to, two central ring supports which are cast solid on the two main bearings. Such central and cylindrical fixture gives complete circular symmetry of shape to the armature, and ensures its symmetric radial straining from change of temperature and from working stresses, while the strain due to its dead weight is allowed for by boring the armature when fixed on its own or similar central supports. The design permits inspection and repair of every part without taking to pieces or lateral withdrawal, by simple rotation on the ring supports. The externally perforated armature yoke-ring is formed of two separately cast rings bolted together, and on each half is cast a circle of outside teeth whereby such rotation for the purpose of repair can be effected. Each side-frame consists of a large central hub on which are cast eight radial arms, and the yoke-ring is bolted between the outer ends of the two sets of arms. The driving torque exerted by the rotating field upon the armature is resisted by a symmetrical concentration of stresses in the main bearings and their fastenings to the foundation.

For lower powers with direct-coupling to slow-running engines, powerful fly-wheel effect is obtained by building the stationary

FIG. 321.—Three-phase Alternator with interior rotating-field—1275 horse-power, [illegible] revolutions per minute.

armature inside and letting the field rotate outside it. In all alternators it is desirable to have a stationary armature in order to have fixed connections throughout the whole high-tension system, and in order to avoid disturbance of the high-tension insulation by centrifugal forces. There is another advantage accompanying external rotating

FIG. 322.—Three-phase Alternator with interior rotating-field—2200 horse-power; 3700 volts; 93¾ revolutions per minute.

fields, namely, that the windings, cores, and pole-pieces do not require specially strong attachment to the yoke-ring that carries them to secure them against centrifugal force, the massive yoke-ring outside them forming a solid abutment against which the centrifugal force presses these parts.

Fig. 323 shows one of these fixed interior armatures on a smaller size of machine, namely, 300 horse-power generating 240 volts at 91 revolutions per minute. This machine carries its own 6-pole exciter on the one end of its shaft. In the middle of the photograph, at the level of the shaft, is seen one of two long strong screwed

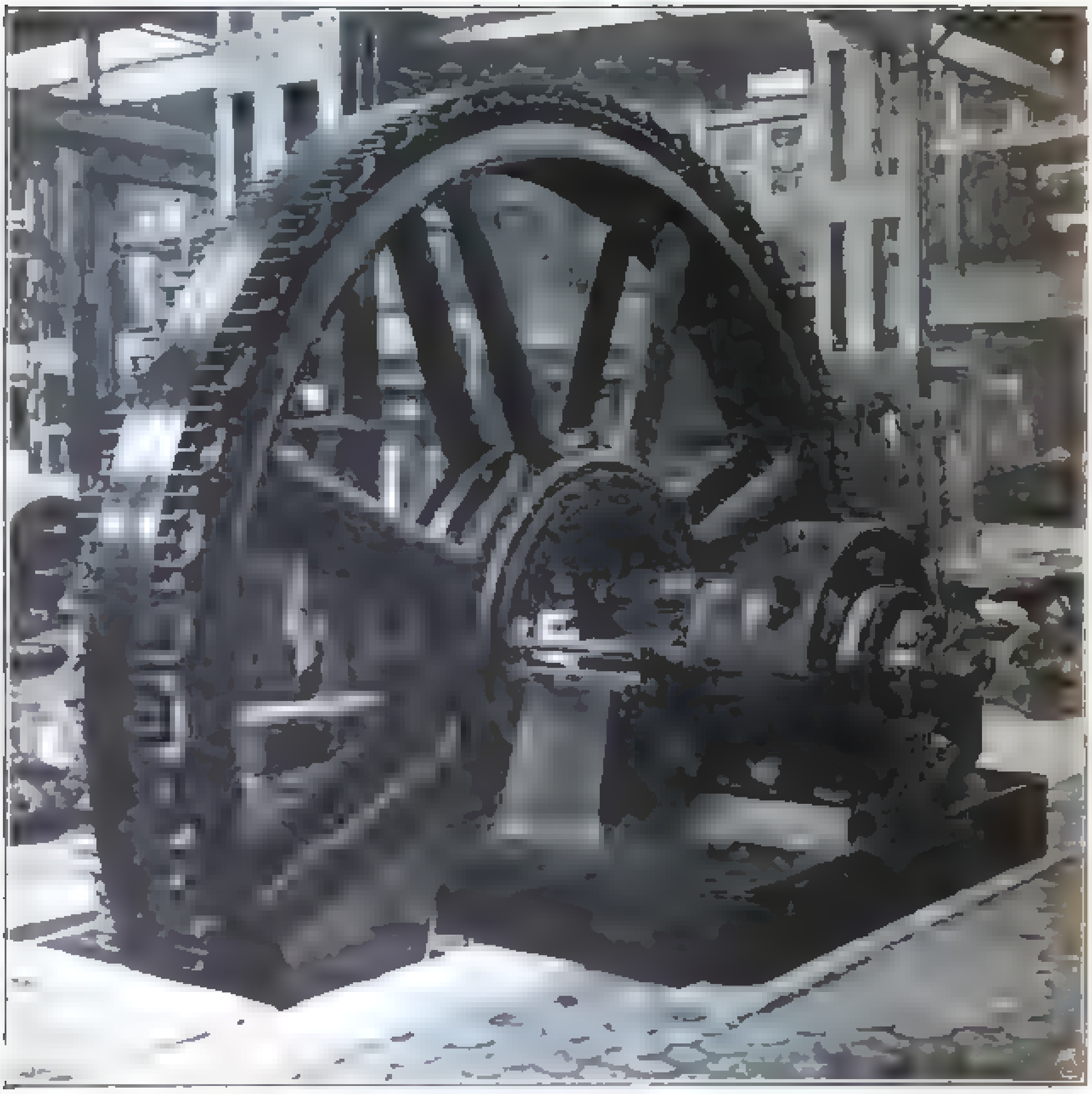


FIG. 323.—Fixed Interior Armature of 3-phase Alternator with exterior rotating-field—300 horse-power; 240 volts; 91 revolutions per minute.

rods (the other similar rod being hidden at the back of the main bearing), by means of which the upper half of the armature can be withdrawn horizontally parallel to the shaft for examination and repair, such removal also giving access to all the magnets of the field. The main bearing has two wing entablatures, upon which

the half-armature slides when so drawn out and rests during the examination and repair.

25. It will be noted that all these Swiss 3-phase railways use low tension upon the contact line and in the motors. This is a most important point. The present writer is entirely in favour of high tension for main-line railways and for urban and suburban railways with heavy local traffic; and, indeed, the 750-volt Burgdorf-Thun installation, because of its being only 25 miles long and having a very light traffic over it, proves nothing, or very little, in respect of the economic practicability of such low-tension driving for really heavy long-distance railway work. But the Swiss lines furnish the most useful evidence regarding the desirability of using 3-phase energy on *tramways*. These low-tension 3-phase motors are heavy per horse-power, but 3-phase construction offers so many very material advantages—which have already been fully referred to, among the most important of them being the low ratio of repairing costs in the motors—that this single disadvantage may easily be overbalanced by the undoubted superior benefits. In conduit tramways there appears to be no difficulty at all in using the two contact rails inside the conduit to carry two of the phases and the track-rails to carry the third phase, because it is well proved that alternating current does not produce electrolytic corrosion such as is feared with rail-return direct current. The 3-phase installation of surface-stud tramways would certainly be difficult and costly. But for overhead contact lines the 3-phase wires would be smaller, and, indeed, invisible at a very short distance. The unsightliness of overhead installations arises a very great deal more from the side poles, the transverse suspension wires, and the guard wires than from the longitudinal contact wires. The former would remain quite unaltered with 3-phase installation, while the two 3-phase contact wires would perhaps be less noticeable than the one direct-current wire of larger size.

26. It is a very remarkable fact that in none of the electric traction hitherto described in this book has any really high travelling speed been attempted, although the examples given are representative of all the work done in Europe, and although the same would still be true if the scope of the book covered American electric traction.

This fact contrasts strongly with the popular idea that the inauguration of electric traction on main lines will mean the introduction of much higher express speeds. So far as actual experience in commercial electric traction has yet gone, the deduction from the historical facts would be in the exact reverse direction. On existing electric railways the highest express speeds, exclusive of stops, attempted or proposed so far have been 60 kilometres per hour, or 37½ miles. This speed is just tolerated on the local trains south of London, and is hardly tolerated anywhere else on steam railways.

It would so far appear that the high-speed electric-travelling idea is due to the uncultured imagination of the masses, whose vague notion of electricity is that it is something that can now do everything that has been hitherto found impossible. It is desirable to consider whether there be any grounds for anticipating future rise of long-distance travelling speed by means of electric traction. That it has raised the average speed, inclusive of stops, of tramway running and of dense city local railway travelling is well proved. The reasons for this improvement have been fully stated in earlier parts of this book. Only a very few of them apply with any force to long-distance travelling with infrequent stops and traffic that is not very dense.

In steam-locomotive travelling, with long runs between stops, express speed, inclusive of stops, is about 50 miles, or 80 kilometres per hour. In such runs on long downhill inclines the speed is frequently 90 miles, or 145 kilometres per hour, that is, about 2½ times the highest speed yet used on electric railways.

The natures of the obstacles militating against high railway speed are not generally understood by the laity, or even by engineers outside railway circles.

The first limitation to safe speed is undoubtedly set by the construction of the road-bed and of the track. The above high steam-railway express speeds have only been very slowly attained by the complete reconstruction of the track—rebuilding the road-bed in very solid fashion, bedding the sleepers more securely in the ballast, using heavy chairs and very substantial fastenings of the chairs to the sleepers, employing 102 lbs. per yard steel rails and very strong and stiff fish-plates. On the Shap incline the present rolling-stock could probably run safely at from 100 to 110 miles per hour if the roadway did not prevent this.

The first obstacle to express speeds higher than those already attained on steam railways, is therefore the enormous cost of rebuilding on more expensive designs the long lengths on which alone such high speeds would be of any possible use.

The obstacle next in importance is the rapid rise of air-resistance with speed. At low speeds the air-resistance to trains bears a moderately small proportion to the total resistance. At low speeds it increases in some proportion not differing greatly from the first power of the speed. In the diagram of speed and air-resistance, however, the curve bends upwards with increasing curvature, so that from 20 to 50 miles per hour it rises, on the average, nearly in proportion to the square of the speed. It appears that the power of the speed according to which this resistance rises itself increases, at least up to some critical speed which has not yet been experimentally investigated. In any case, it is now a well-established fact that the curve bends upwards so much that at maximum railway speeds the

air-resistance is by far the most important part of the total. It is the excessively rapid rise of horse-power required with increase of speed above present low express speeds that makes such increase much beyond the already attained limits commercially difficult and probably impossible. Here, again, the physical difficulty to be surmounted has no relation of any sort to the kind of propelling power employed, whether steam or electricity.

The third obstacle to such increase of speed is, in the author's opinion, dependent on the spring suspension of the carriages and locomotives with their underframes upon the wheels or the wheel-axles. Under specified road-bed and track conditions, the danger of derailment is diminished in almost exact proportion to the completeness with which the heavy overlying masses are guarded against shock arising at the rail-surface, and the degree in which such shocks are confined to the relatively light masses of wheel and axle. The safety against the wheels mounting and riding upon the rails depends upon the quickness with which these are thrust down upon the rail by spring pressure, and this quickness is greater the smaller the mass so pressed downwards. The ideal arrangement is to have the wheel rims and tyres alone forced to follow the irregularities of the rails, and to have axles and all the remainder of the load spring-borne. The calculations for the vibratory motions of the wheels and of the spring-borne mass have been given in a previous chapter. Here, again, there seems to be little choice between steam and electric driving.

The fourth hindrance to high speed is the existence of curves on all our railways. In the trials cited below no speed above 170 kilometres per hour was permitted on the curve of 2 kilometres radius, although this was protected by guard-rail throughout. Here, again, electricity and steam are exactly on a par.

27. The fifth difficulty to be overcome by steam trains at high speed is the great boiler-power required for the long runs on which alone very high speed is useful. It is the boilers that get exhausted long before any other part of the locomotive. This led in the United States of America to the mounting of enormous boilers on the locomotives as soon as they had road-beds and tracks fit to carry the extra load. This movement has been followed in Great Britain, but under exceptionally difficult constructive conditions due to the tunnels being dimensioned for comparatively small-sized locomotives only. The increase of weight of locomotive aggravates naturally the difficulty in respect of strength and solidity of roadway.

Here we find the first material advantage possessed by electric over steam traction. The former does not carry coal or water or any power-generating material with it. The motors increase in weight with the horse-power demanded of them, but not with the length of time or running distance between stops.

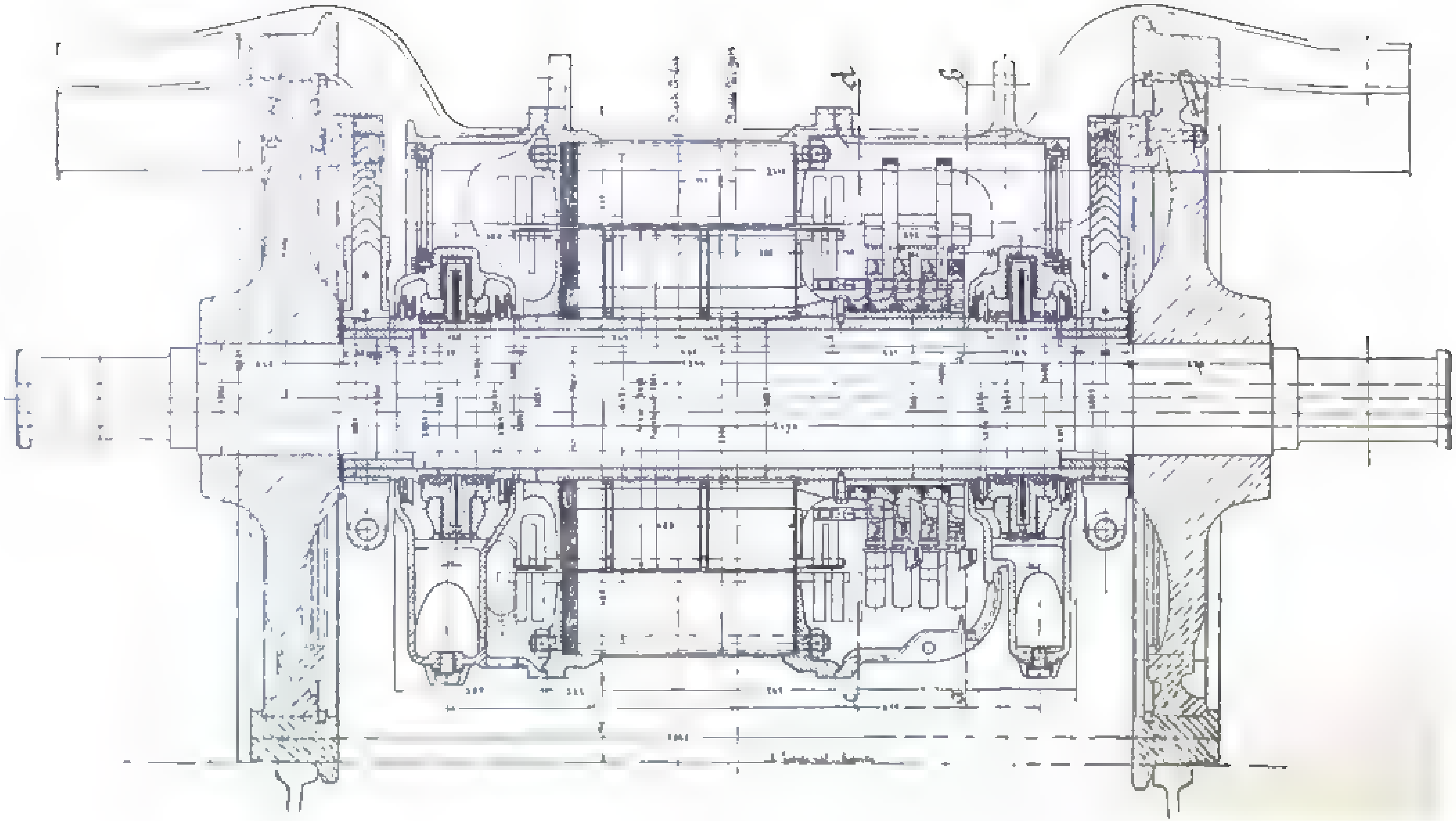


Fig. 324.—Allgemeine Elektricitäts Gesellschaft Motor and Spring-drive—Zossen High-speed Trials.

And yet many, perhaps most, of the modern proposals for high-speed electric railways proceed upon the plan of placing upon the cars or locomotives excessively heavy transformers, and even motor-generators, accumulators, and a second set of direct-current motors. Such proposals neutralize the above first important item of superiority in electric motive power.

The reciprocating action of the engine of a steam locomotive produces lurching oscillation, however well "balanced" the reciprocating and revolving masses may be, which is one of the causes of derailment at high speed. The mechanics of this question cannot be entered upon here, but it may be noted that much of the practical effect results from the necessity of spring mounting between the wheels and the frame which carries the engine. Part of the oscillation is due to the non-uniformity of the driving-torque, what is termed technically the transverse rocking moment due to the alternate action of the two engines on the two sides of the machine being the most dangerous feature of this non-uniformity.

This gives a second advantage to electric over steam driving, the driving-torque of a well-designed electric motor being almost perfectly uniform. But in several of the most recent designs of electric locomotives the motors drive the wheel-axles through cranks and connecting-rods; and this plan again reduces the superiority originally inherent in the electric motive power.

In electric traction there has been found a superior adhesion-coefficient between the driving-wheel tyres and the rails. The author's belief is that this must be entirely due to the more uniform driving effort applied and to the easier spring suspension that has been common in electric tramway traction. This must result in less jumping and less slipping of the wheels upon the rails, with the accompanying advantage of always, or more constantly, calling into action the frictional coefficient of "rest," which is greater than that acting during sliding. Actual jumping upon the rails must involve the loss of a large proportion of driving energy.

28. Electric high-speed trials have been proceeding for some years outside Berlin. According to Mr. Alexander Siemens' paper, read in May, 1904, to the Institution of Electrical Engineers, the idea originated as far back as 1886 in a Siemens-and-Halske patent for the use of high-tension alternating current transmission with transformers either along the line or carried on the train.

The experiments were actually commenced privately in 1892 by Herr Wilhelm von Siemens, and were renewed in 1897 by Siemens and Halske. In 1899 a syndicate was formed among several strong financial and engineering German firms for the prosecution of the trials, and in the same year the War Office of the German Government placed at the disposal of this syndicate for the purpose of these trials the

23-kilometres-long military railway between Zossen and Marienfelde, near Berlin. The practical work has been carried on, under considerable Government restrictions, by the two firms Siemens and Halske and the Allgemeine Elektricitäts Gesellschaft, both of whom are members of the syndicate and who entered into a friendly competition in the endeavour to obtain successful high-speed running with their respective cars.

The Siemens and Halske coaches have been modifications of the general patterns already illustrated for the Berlin railways, adapted for high-tension 3-phase motors with transformers carried on board.

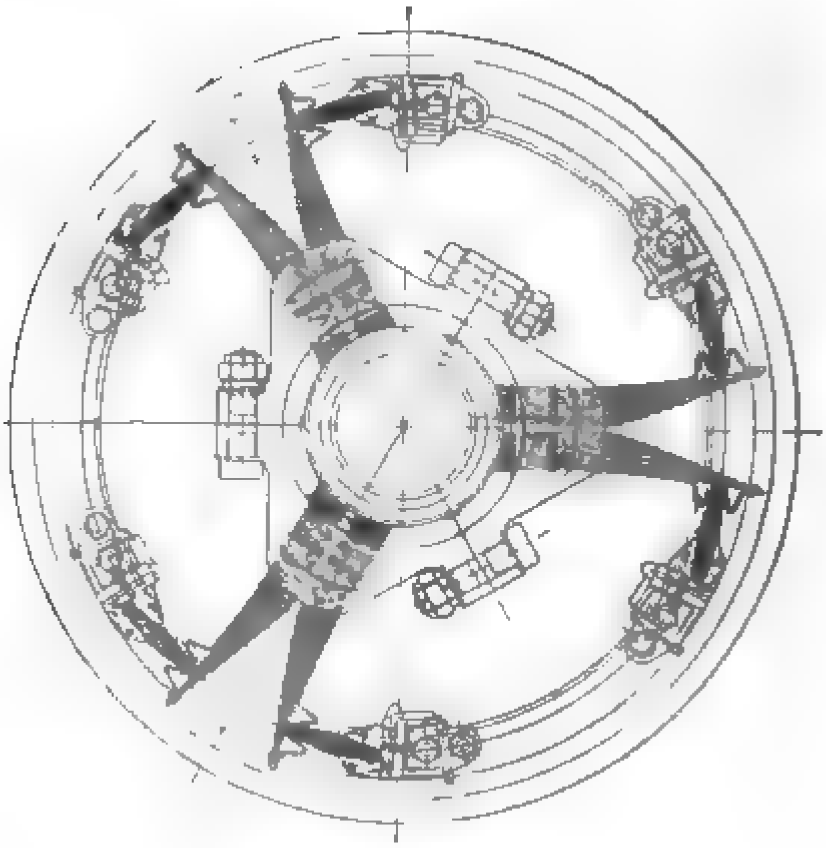


Fig. 325.—Allgemeine Elektricitäts Gesellschaft Spring-arm Drive between Rotor and Wheel—Zossen High-speed Trials.

The A.E.G. cars have been fully described by Herr Lasche in a paper read before the Institution of Electrical Engineers in 1901 (see vol. 31, part 153). The motors are placed centrally on the wheel-axles. The stator is fixed rigidly in the underframe of the truck, and in this also are fixed rigidly the bearings of the rotor. The rotor has a hollow shaft, after the manner of the Ganz motors described for the Valtellina line. The wheel-axle has a diameter of 180 millimetres, and the smallest inside diameter of the rotor shaft is 206 millimetres, giving a free play between the two from concentricity of 13 millimetres, or 26 millimetres from side to side. Ten millimetres is the eccentric deflection calculated to be

allowed by the spring supports. The bearings in which the rotor hollow shaft runs are 260 millimetres in diameter. On account of this large size and the high speed, special ring-disc lubrication is supplied. The rotor shaft drives the running-wheels at each side by three spring arms, whose outer ends are set in slide-blocks sliding in radial slots in the arms of the wheel. Fig. 324 is a cross section of the motor and wheel-axle, and Fig. 325 shows one design for the spring arms, modified from that actually used by the introduction of thrust-shackles between the spring arms and the wheel-rim in place of the radial sliding blocks. In Fig. 326 is shown the spring suspension

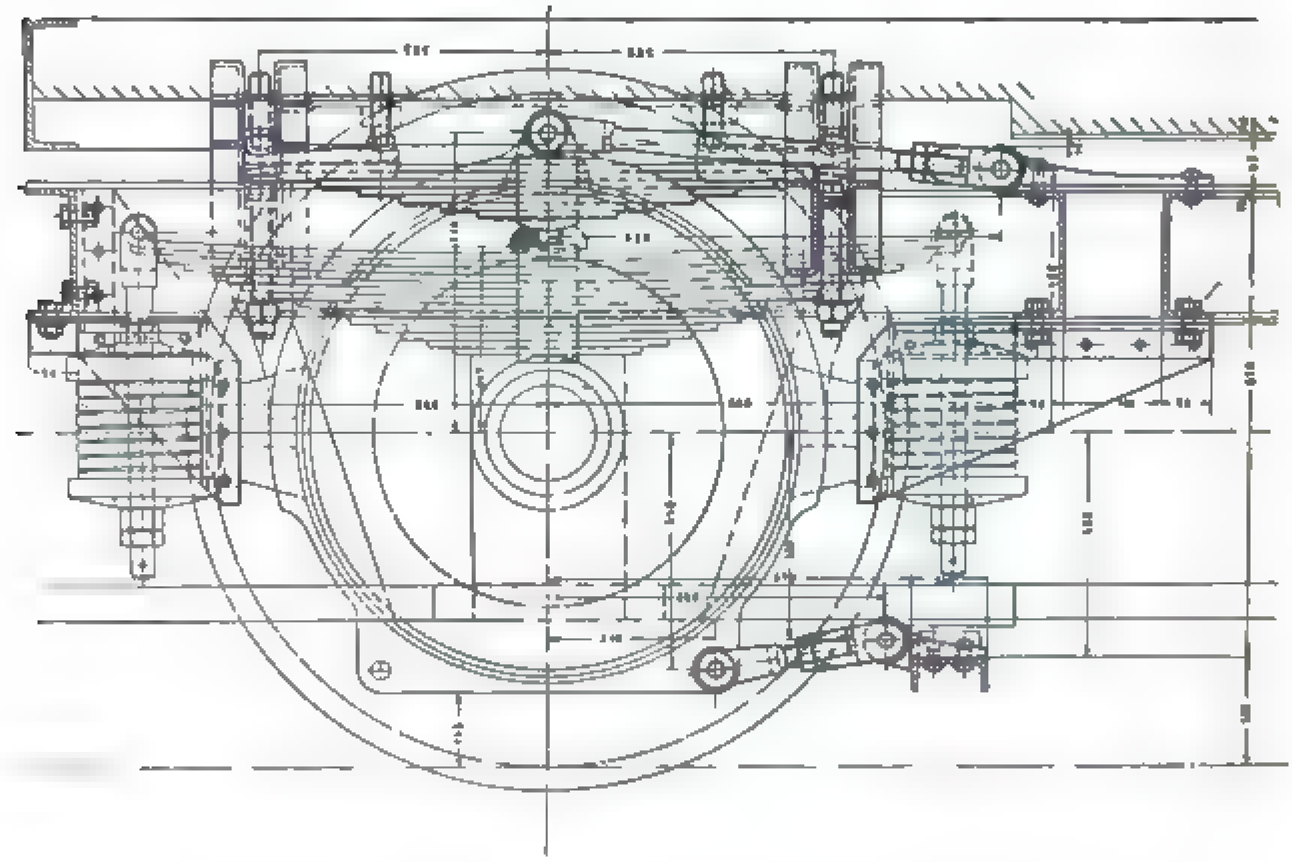


FIG. 326.—Allgemeine Elektricitäts Gesellschaft Car Spring-suspension—Zossen High-speed Trials.

between the axle-boxes and the underframe and between the underframe and the car-body.

It must be observed that Mr. Lasche described these designs before they were in actual use in the high-speed trials on the line, although after they had been under test in the Allgemeine Elektricitäts Gesellschaft works. As only 10 millimetres deflection is allowed by the free space between the hollow shaft and the wheel-axle, it seems evident that these two must knock against each other whenever the spring suspension of the underframe upon the axle-boxes would allow of a greater deviation from mean deflection than this. This spring suspension is arranged so as to be very flexible throughout

the first 3 or 4 millimetres deflection, and to become much stiffer for greater deflections than this; but it can hardly be supposed that the shocks incidental to speeds of about 200 kilometres per hour do not need, with even the best laid roadway, more than ⅜-inch deflection of the spring joint between the comparatively light wheels and axles and the very massive motor and underframe together.

29. Fig. 327 is an elevation of the A.E.G. car used, and Fig. 328 is the plan of the same. It is placed on two 3-axled bogies. A 250 rated horse-power motor drives each axle, so that in all the car is supplied with 1500 rated horse-power. The same rated size of motor was placed on the Siemens coach, and the short-period overload capacity is stated to be over 4000 horse-power during acceleration.

Both the Siemens and the A.E.G. cars carried transformers. These transformed the line voltage down to 650 volts. The A.E.G. motors were designed for 435 volts, and the Siemens for 1150 volts.

The line voltage was varied in the trials from 6000 to 14000 volts, and the periodicity from 25 to 50. The current is brought along three overhead wires ranged one vertically over the other at 1 metre vertical spacing apart, as seen in Fig. 327. It is collected by two sets, each of three sliding bow-collectors. In the A.E.G. car these are mounted on six separate vertical standards, while in the Siemens plan each set of three is carried by one standard. The wind-pressure on the Siemens collector arm is balanced by extending the arm a short distance on the other side of the standard and mounting a wind-pressure plate upon this short arm.

The running-rails act as a fourth conductor, and a special feeder cable is connected at intervals between them. The function of this fourth line is, however, merely to keep at earth potential the star-junction of the three phases beyond each motor, and thus to keep the three active phases in good balance as regards phase-difference and quantity of current.

30. The first trials were made in the autumn of 1901, when about 2200 kilometres were run electrically.

Previous to this the road-bed had to be practically relaid, the original track being unsuitable for anything over 80 kilometres per hour, and the rails being only 33½ kilograms per metre, or 66 lbs. per yard. In November, 1901, the speed of 160 kilometres = 100 miles per hour was reached, but even speeds of 140 kilometres knocked about the road so badly that any speed above 130 kilometres was forbidden on subsequent runs. Above 100 kilometres speed the rails were depressed, according to measurement, 6 to 7 millimetres, or ¼ inch, when the train passed.

The way was not relaid in time to renew trials at over 125 kilometres in the year 1902; but since that date the road-bed has been entirely relaid with stone ballast and rails of 41 kilograms per metre,

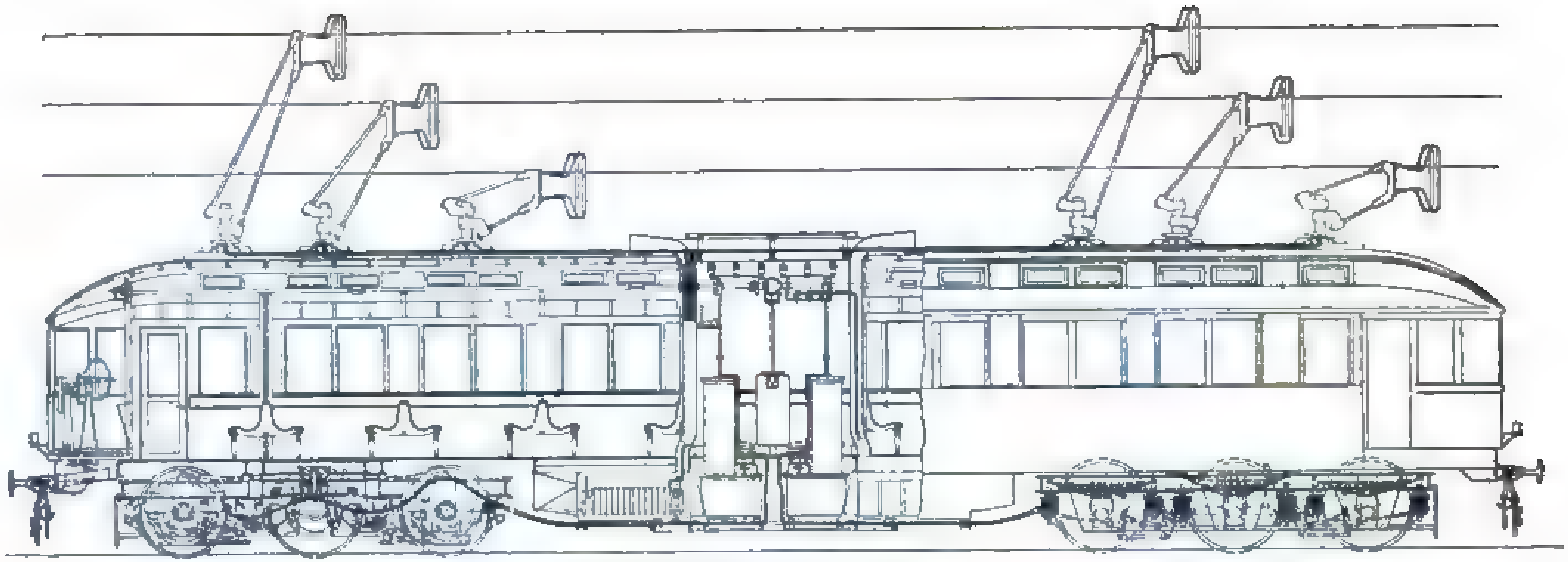


Fig. 327.—Elevation.

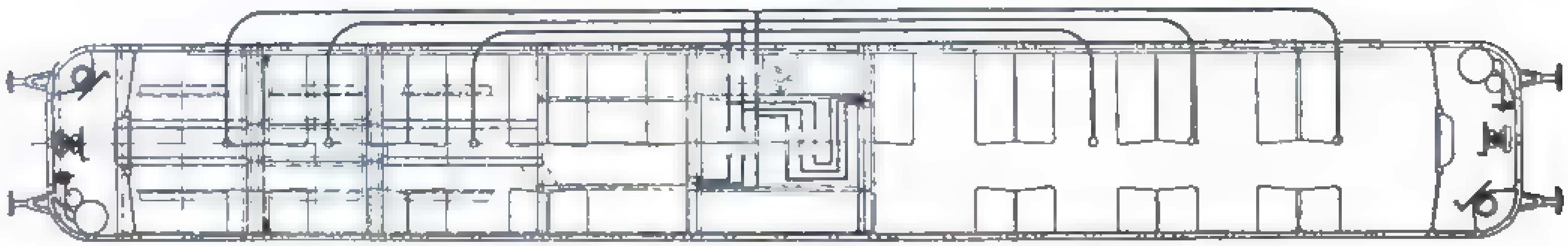


Fig. 328.—Allgemeine Elektricitäts Gesellschaft Motor-coach—Zossen High-speed Trials—Plan.

equal to 81 lbs. per yard, with guard-rails all along the whole length of the route. With an improved construction of car with longer wheel-base and easier spring suspension, and an important modification in the design of the bow-collector arms, 210·2 kilometres, or 131 miles, per hour speed was reached on October 28, 1903. This record was reached by the A.E.G. car with a periodicity in the energy supply of 47½ per second, and a 6-per-cent. slip of the motors. The car swayed so much, however, that one of the overhead wires was broken. On November 11 the Siemens car reached 208 kilometres per hour speed, with 45·3 periodicity and 2·8-per-cent. slip in the motors.

The trial line has one curve of 2000 metres radius upon it, but not over 170 kilometres per hour speed was permitted on the curve.

In a run on which 201 kilometres per hour was reached by a Siemens car without any damage being done either to the line or to the car itself, 2300 kilowatt power was used during the acceleration period. The voltage was 14000 and the periodicity 46. The speeds of 80 and 120 kilometres were reached at the ends of the first and second kilometres, and the curve was passed at 170 kilometres per hour. At 7 kilometres the speed of 185 was attained, and 195 kilometres per hour was reached without increasing the power above 2300 kilowatts. The 200-kilometres-per-hour speed was reached with 2400 kilowatts.

31. In tables given in Mr. Alexander Siemens' paper, and extracted by him from the official report of the Syndicate, measured and calculated results are given, of which the following may be taken as a *résumé*. From measurements taken in an A.E.G. car on the acceleration periods, the maximum speeds attained ranged from 156 to 210 kilometres per hour, with current frequency ranging from 36 to 48 per second; while the horse-power at the bow-collectors on the cars ranged from 1890 to 2770. The rates of average acceleration ranged from 0·123 to 0·197 metre per second-second; but these did not follow the variation of horse-power, probably because of varying head-wind. For instance, the minimum acceleration 0·123 occurred along with the maximum wind of 4·8 metres per second.

On the Siemens car the horse-power varied from 1925 to 2900, while the maximum speed varied from 162 to 206 and the current frequency from 36 to 46. The range of acceleration was from 0·114 to 0·196. Head-winds of 4·9 and 5·9 metres per second were encountered, but these did not coincide with the lowest acceleration.

While running at constant speed with the periodicity of the current ranging from 36 to 40, the average speed of the A.E.G. car varied from 163 to 182 kilometres per hour, and the horse-power collected at the bows ranged from 1270 to 1985. The maximum average speed of 182, however, took only 1470 and 1575 horse-power on two readings. The voltage at the feeding-point varied from

9460 to 10930, and the ampères from 92 to 113 with cos ϕ ranging between 0·63 and 0·83.

At constant speed the Siemens car ran at average speeds from 161 to 180 kilometres per hour, with from 1355 to 1875 horse-power, the frequency being always 36 except on the trial in which the 180-kilometres average speed was reached when it was 40. Here, again, the horse-power did not consistently rise and fall with the speed; in fact, identically the same horse-power, namely 1875, was taken with both the lowest and the highest speeds. At the same time the voltage at the feeding-point varied from 9200 to 10250, and the ampères from 83 to 109, with cos ϕ ranging between 0·72 and 0·86.

These two cars were practically of the same weights, 93·4 and 94 tons; and the above readings show no important practical differences between their electrical or mechanical efficiencies.

32. The final result, so far, of these trials seems to be that they have induced Messrs. Siemens and Halske to abandon transformers upon the car, and to use lighter and higher-speed geared motors with more ordinary spring suspension. They are now experimenting with a small locomotive fitted with two high-tension (10,000-volt) 3-phase motors, in order to do away with the weight of the transformers carried on board and also with the expense of duplication of the transmitting line and of sub-stations involved in placing transformers at intervals along the road. The motors are geared in the ratio 1 to 2, and have spring nose-suspensions somewhat after the normal tram-car pattern. In June of 1902 this locomotive was run successfully at 10,000 volts. Pulling a 70-ton train at 102 kilometres per hour, about 300 kilowatts was measured at the feeding-point, the voltage being about 10,800 and the ampèrage about 19, while cos ϕ, as calculated, was a little over 0·8. Later results with this system of traction have not yet been published.

33. During the last few years there has been much talk of using single-phase transmission for electric railways. Mr. Mordey reports that an experimental single-phase electric railway at Oerlikon has been successful; and he and Mr. B. M. Jenkin read a paper in 1902 before the Institution of Civil Engineers, arguing in favour of this system. The "Union Elektricitäts Gesellschaft" of Berlin are now running a short line with single-phase energy. Heyland single-phase induction motors have been put on the market by Messrs. Witting Bros. in this country, and have had success for stationary driving under favourable conditions. The difficulty is in starting such motors on a large resisting torque. Messrs. Brown, Boveri and Co. have recently developed a single-phase commutator motor which, for any one setting of the brushes, gives its greatest torque at zero speed, the torque diminishing almost uniformly as the speed increases, and the horse-power thus varying with increasing speed according to an

approximately elliptical curve. The horse-power thus rises to a maximum at about eight-tenths of the normal speed, and then falls with higher speeds. The initial zero-speed torque is varied by the setting of the brushes. The controller manipulation appears to be extremely simple, since no starting resistances are employed and all that has to be done is to shift the brushes. By suitable manipulation either constant speed may be maintained with varying torque to meet varying resistance due to changing gradient, head-wind, or curves, or else constant torque may be obtained with changing speed, as may be desired during the acceleration period.

So far as electric traction is concerned, however, these efforts with single-phase energy are at present in too early an experimental stage to allow of this volume being considered a suitable vehicle for describing or discussing them, no commercial tramway or railway being actually in existence worked on this system.

THE END

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